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The Identification Of Potential Applications For Robotics and Remote Control Systems in Canadian Mining

Volume 1 of 2

July, 1982

MICROMEDIA

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September 8, 1982

Mr. R. J. Welwood
Assistant Director, Mining
Minerals Research Program
CANMET
555 Booth Street, Room 127
OTTAWA, Ontario
K1A 0G1

Dear Mr. Welwood:

Enclosed is our final report on "The Identification of Potential Applications for Robotics and Remote Control Systems in Canadian Mining."

The report is divided into two volumes. The first volume summarizes the industry awareness and interest for the use of robotics and remote control in mining. Individual mining operations and their interests are identified throughout the report. Volume two is the Appendix which consists of the contact reports. The contact reports are abbreviations of conversations which took place between interviewers and respondents and represent the opinions of the respondent and not necessarily that of his company.

Given the preliminary nature of this study, there was considerable interest expressed by many of our contacts in mining and government in the results of this study. Many of the contacts had not previously thought of robotic applications in the mine.

The report is primarily an overview of the subject. There is a need to conduct further evaluations of the individual potential opportunities in the study.

Yours sincerely,

G. M. Robertson, P.Eng.

/tm
Enclosure

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RobertsonNickerson Limited CONSULTING ENGINEERS & MANAGEMENT CONSULTANTS
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THE IDENTIFICATION OF POTENTIAL APPLICATIONS FOR ROBOTICS AND REMOTE CONTROL SYSTEMS IN CANADIAN MINING

1.0 EXECUTIVE SUMMARY

1.1 Objective

To evaluate the mining industries' current status and level of interest in robotic applications, and to make recommendations and suggestions with respect to a possible role for EMR/CANMET in serving the industries' needs.

1.2 Scope

The study focused on Canadian mining, machinery manufacturing, and service companies. Over 100 contacts were made in the industry including field interviews and mine tours with all the major mining companies. Limited contacts were made in the United States to provide a broader perspective on mining robotics potential.

The study overviews the mining industries' awareness, areas where they envisage potential and their perception of EMR's possible role. The economic viability of a Canadian mining robotics industry is not evaluated in this preliminary analysis of the industry. Much of the initial work was an educational process whereby the concept of robotics had to be conveyed to the mine personnel.

1.3 Report Highlights

- The level of robotics awareness in the Canadian mining industry is in the infancy stages.

- There is a grey area in the definition of a mining robot, hard automation and remote control.

- The industry is initially negative to the concept of mining robotics, yet, as the awareness level is increased, they are able to suggest many potential application areas.

- The mining industry perceives potential for short term robotization of existing operational mining machinery and a longer term potential for development of integrated robotic/ automated continuous systems.

- The area that is perceived to have the greatest potential for robotic application is underground mining.

- The mining industry has suggested various short term levels of robotization for:

    - drilling
    - explosives handling
    - ore removal
    - ground conditioning
    - raise boring
    - continuous miners

- Long term robotization is seen to involve telechirics and continuous mechanical mining technologies.

- Factors that will play a major role in the development of the mining robotics industry are:

  - safety
  - productivity
  - labour
  - mine uniqueness
  - economic climate
  - Canadian innovation
  - robot technology

- Priority areas in the development of mining robots are:

  a) Short Term

  According to Activity
  - scaling
  - rock bolting
  - ore removal
  - drilling

  By Research Activity
  - development of existing remote control systems for application to other mining machinery.
  - sensor development
  - development of sturdy robotics
  - design of mobile robots

b) Long Term

- Identification of technologies that may offer integrated continuous operation for Canadian mines.
- Development and test of hardware concepts for continuous mechanical mining of hardrock.

Robotics will play a significant role in these future technologies.

- EMR's support of mining robotics is viewed as part of the mechanism for maintaining Canada's position and role in the international minerals market.

- An EMR sponsored mining robots program would act as a catalyst towards the development of robot technology. The national program would consist of four subprograms:

1) promote and focus R&D on productivity and safety enhancement through robotics and remote control;

2) ensure that all key players in the Canadian mining industry are kept aware of robotic developments;

3) organize and support a joint effort engaged in mining robot applications development;

4) Encourage mining robot manufacture as a commercial venture.

1.4 Recommendations

The following recommendations are based upon analysis of the information obtained from industry and government contacts. The recommendations made in this section address the various EMR/CANMET activity options, that will focus efforts of all participants in the development of mining robotics.

We recommend that EMR/CANMET;

- Establish a steering group to direct the development of robotics.

- Undertake an analysis to determine the commercial viability, including market and production variables, of identified priority areas.

- Along with the U.S. Bureau of Mines, jointly sponsor detailed mining robotic workshops to further expand upon potential robot applications that will be applicable throughout North America.

- Undertake detailed technological evaluations of potential robotic implications in each of the identified priority areas.

- Examine the short term and long term parameters and viability of a joint effort application group dedicated to the development of mining robotics.

- Initiate robotic research and development in the specified priority areas through joint government/industry/academic efforts.

- Develop the mechanism for maintaining the mining industries' awareness of robotics.

- Identify and initiate discussions with companies and other participants interested in forming a joint effort application group.

- Identify companies that could spearhead and coordinate activities of the joint effort application group.

- Initiate a program to provide financial incentives to the commercialization of mining robotics through a combination of direct grants and loan guarantees.

2.0 BACKGROUND

2.1 Project Scope

During the last decade, mining technology has been dominated by a trend common to all industry that has largely replaced manual methods of operation by mechanized and, to a considerable extent, by automated processes.

This analysis evaluates the mining industries' current status and level of interest in robotic application, and makes recommendations and suggestions with respect to a possible role for EMR/CANMET in serving the industries' needs.

The technical areas covered include:

a) man-in-the-loop, and man-out-of-the-loop robots;

b) remote control devices which have an order of intelligence and programmed decision-making capability.

Primary data collection is based on on-site and telephone interviews with mining engineers, distributors, producers, and associations throughout Canada, and to a limited extent in the United States. All the major Canadian mines were contacted and personnel interviewed during the course of the survey.

Secondary data sources included government statistics and resources, published literature, associations and various industrial and academic data banks.

The following portions of this chapter overview the Canadian mining and robotics industries. Since there is an apparent dichotomy of the two groups, and since the reader may require a general industry knowledge to fully comprehend the implications

of this report, the current status of both the mining and the robotics industry is briefly reviewed prior to the analysis of mining robotics potential.

2.2 What Are Robots and Remote Control Devices?

The Robotic Institute of America (RIA) defines a robot as:

> "A reprogrammable multifunctional manipulator designed to move materials, parts, tools, through variable programmed motions for the performance of a variety of tasks."

The key point is that a robot is a machine guided by a program which can be altered to provide flexibility to an automated-mechanized system.

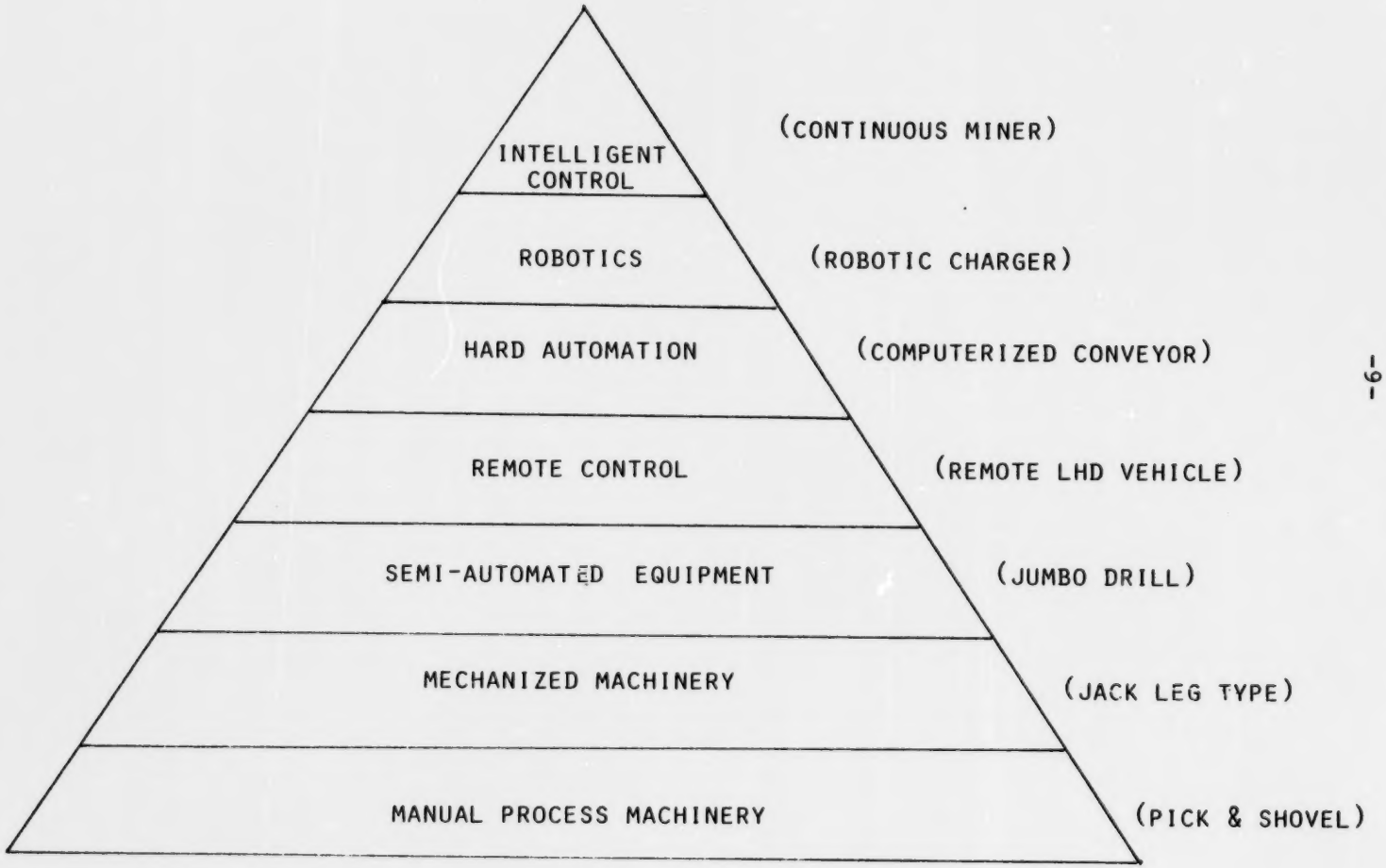
The applicability of the above definitions in the mining context is confused due to the mining industries' conceptualization of the technology tree (Figure 1).

This report is primarily concerned with those equipment developments including and above those in the tree delineating high level automation. Automation means the creation of technical processes which do not require human action, either continuously or at an enforced rhythm for their performance. Automation can be applied either to complete systems or to parts of a process. Automated processes are usually rigid, laid down work processes.

Remote control is a stage in the automation process. The term remote control is used to describe the operation of machines where the operator is stationed at a distance away from the vehicle or machine. It includes machines having an umbilical cord between the operator and the vehicle.

FIGURE 1

THE TECHNOLOGY TREE APPLIED
TO THE CANADIAN MINING INDUSTRY



Robotics is the forerunner and a component of process or intelligent control. Intelligent control is a technical process which is controlled automatically and optimized by means of a computer.

> "There is a fine line between automation and mechanization, i.e., no one gets excited about a microprocessor on a forklift, but it is just as important as a robot"
>
> Industry, Trade & Commerce

2.3 The Existing Industrial Robot Industry

2.3.1 Types of Robots Currently Available

Essentially, there are three levels of robots now available in the marketplace:

1) Simple Robots
2) Medium Technology Robots
3) Sophisticated Robots

1) Simple Robots

Pick and place robots and fixed sequence manipulators are simple robots. Typically, they are restricted to three or four degrees of freedom and have a limited control sequence.

These robots are relatively inexpensive, easy to maintain, simple to program, and generally unsuitable for use in a mine.

2) Medium Technology Robots

Medium Technology Robots have typically four to six degrees of freedom and greater memory capacity.

They are servo-controlled which means having internal sensors which can measure position, velocity, force and so forth.

These robots are more expensive and are typically used in load-unload applications.

3) Sophisticated Robots

These robots are highly flexible, programmable manipulators which can be programmed to operate anywhere within a designated, fixed area.

The "brain" of the robot can be a simple micro-processor or a complex mini-computer. The sophisticated robot may be taught the desired sequence of movement by leading the arm through the steps.

Modular components are also available to allow interchangeability of end tools.

Figure 2 demonstrates a typical industrial robot.

A robot does the work it has been instructed to do by memory of its instructions. Some of the tasks which are on the threshold of being done by the more sophisticated robots are:

1) adaptation of handling operations to observations of positions in 1 or 2 dimensions, by touch or sight.
2) simple pattern recognition.
3) simple assembly operations.
4) self steering and fine self positioning

Even in these cases, however, the robot is still slower and less adaptive than the human.

More sophisticated skills, such as the following have not as yet been mastered:

1) Diagnosis of location and type of fault breakdown in machinery.

2) Recognition of a 3-dimensional object and of its position and orientation.

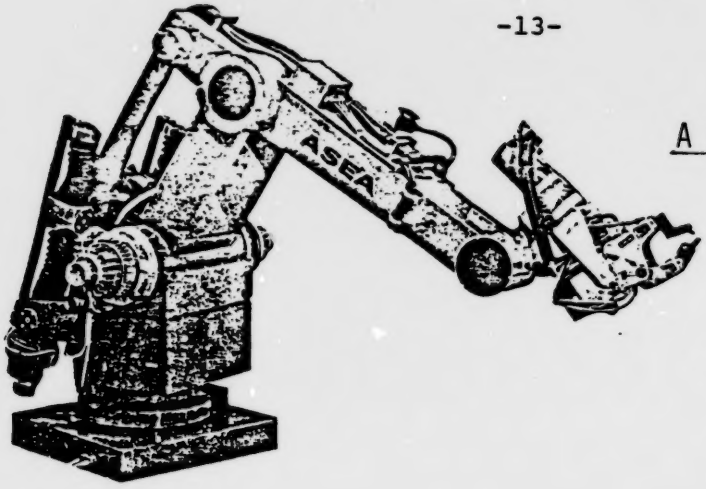
3) Selection of an action to an unexpected situation.

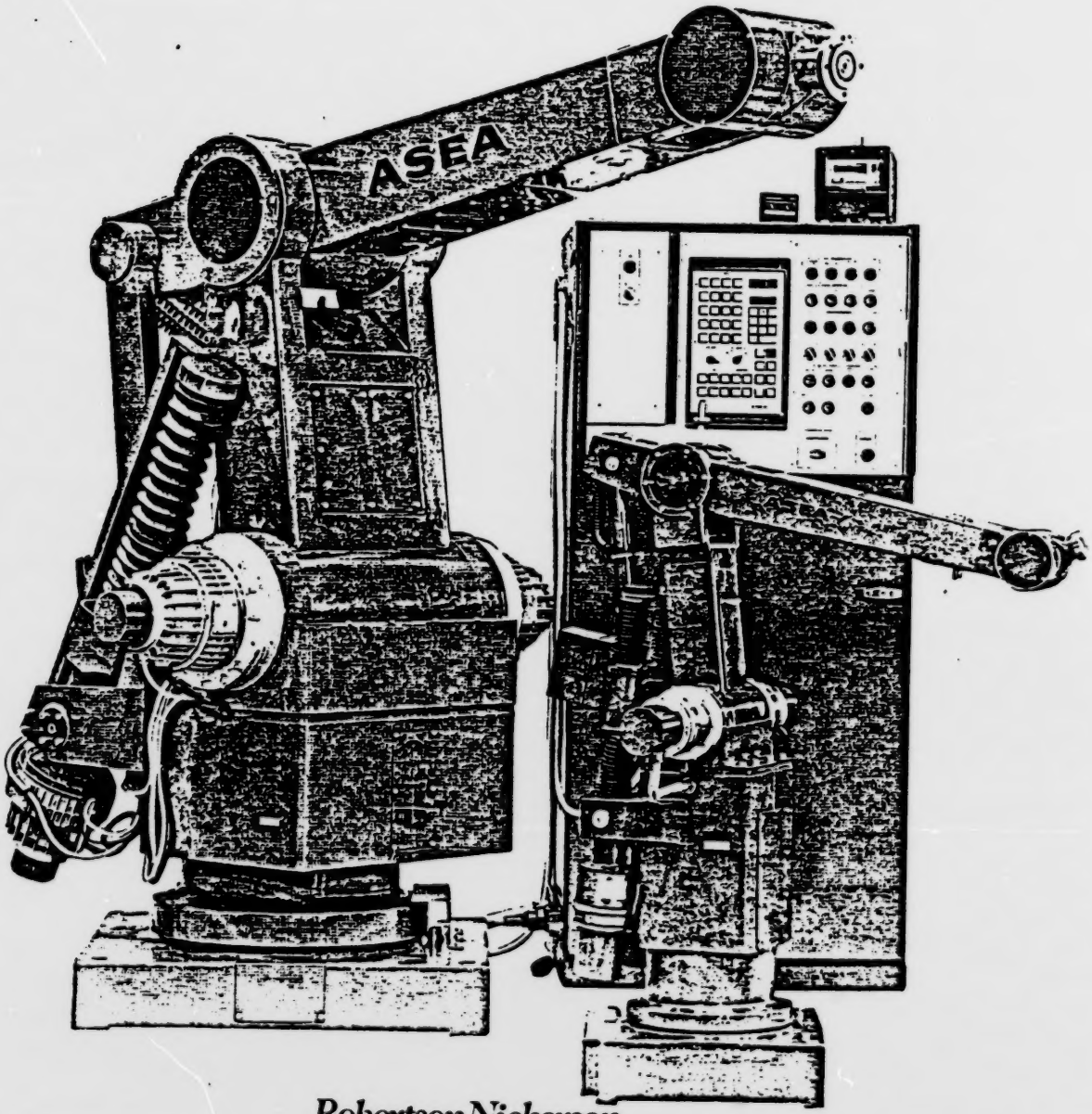
4) Non-repetitive or complex operation.

<u>It should be noted at this point that the above mentioned "sophisticated" skills are typical of day to day requirements in a mining environment.</u>

FIGURE 2

A TYPICAL INDUSTRIAL ROBOT





2.3.2 End-Users and Applications

The predominant end-use of robots is the automotive industry. In Canada, this industry accounts for an estimated 63% of total installations.

Current robotic applications include spot welding, arc welding, spray painting, material handling, parts assembly, inspection, molding, and machine tool processes. Welding robots are the most prevalent of all robots installed.

The applications for manufacturing robots are undergoing constant dynamic change. New applications and an expanding market population are increasing the opportunities for robotics. To date, there has been little robotic penetration of non-manufacturing markets.

> "We are busy enough selling manufacturing robots, which provide the best return on the money."
>
> Cincinnati Milacron

2.3.3 Industrial Robotics Markets

Japan is the world leader in both the manufacture and installation of industrial robots. Figure 3 depicts the industrial robot population by country.

Figure 4 identifies the number of installed robots, and the production of robots in Japan, the United States, and Canada.

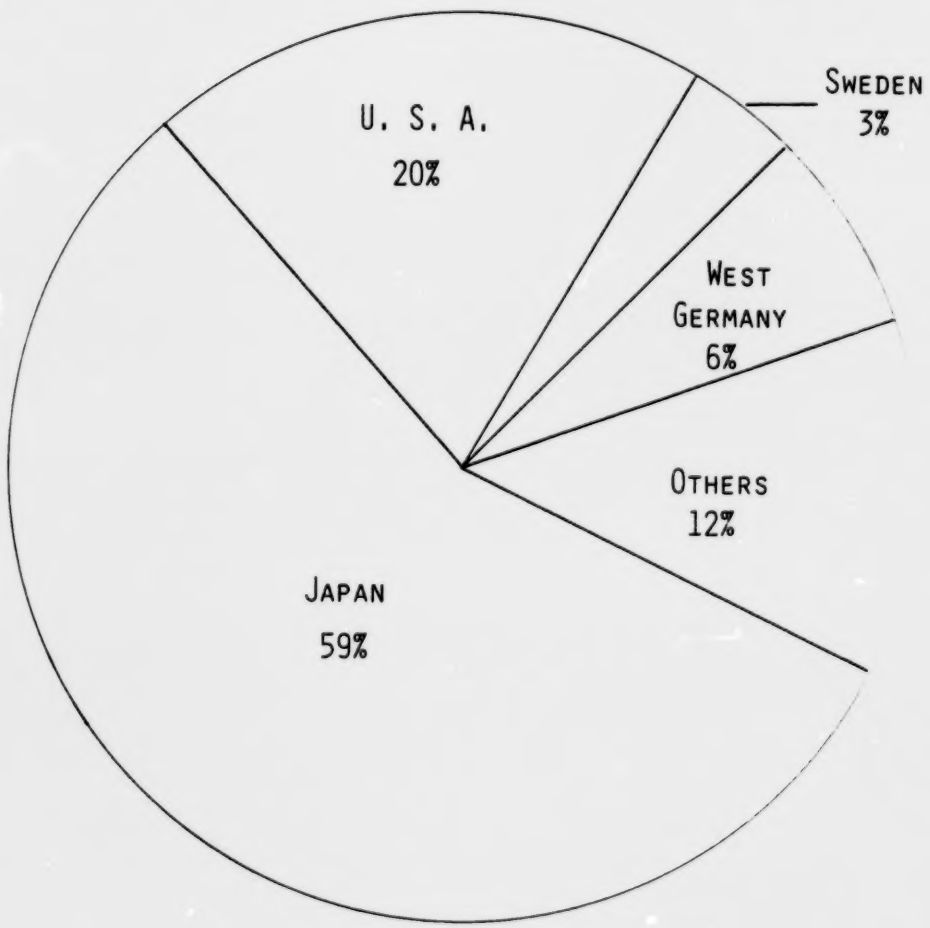
Robotics is an industry that is still in its infancy stages, and predicted to experience exponential growth rate. Table I illustrates expected increase in industrial robots.

FIGURE 3

POPULATION BREAKDOWN OF ROBOTS

BY COUNTRY

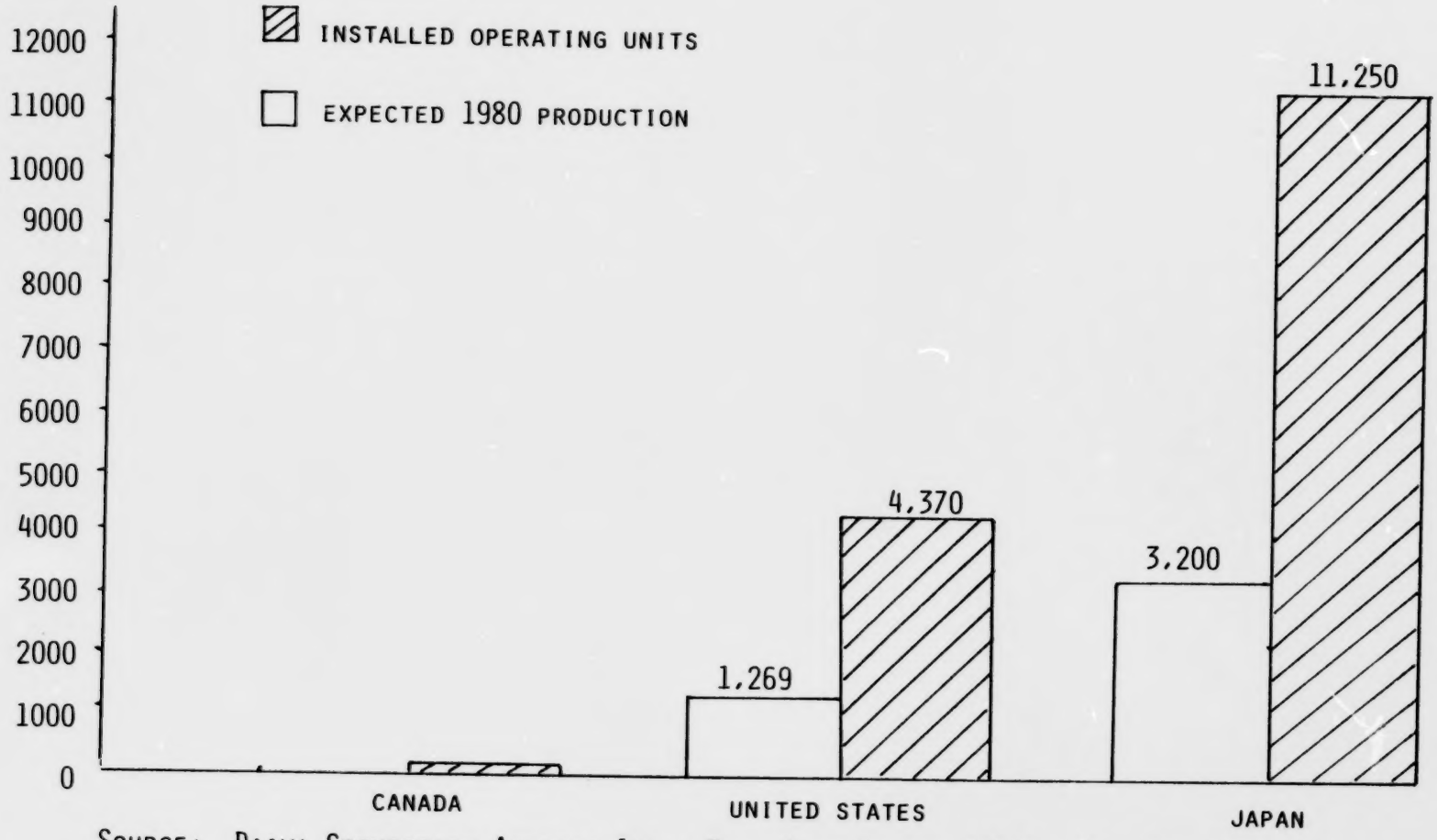
(EXCLUDES MECHANICAL TRANSFER DEVICES)



SOURCE: IRON AGE, MARCH 19, 1982, PG. 64

FIGURE 4

INDUSTRIAL ROBOTS (U.S. DEFINITION) 1980



SOURCE: DAIWA SECURITIES AMERICA INC., PAUL ARON REPORT (#25), JULY 28, 1981
RNL, NRC ROBOTIC REPORT, AUG. 1980

TABLE I
INDUSTRIAL ROBOTS (U.S. DEFINITION)
BY UNITS AND VALUE

CATEGORY	1980	1985	1990
Units			
United States	1,269	5,195	21,515
Japan	3,200	31,900	57,450
Value ($x 000,000)			
United States	101	441	1,884
Japan	180	2,150	4,450

Source: Daiwa Securities America Inc, Paul Aron Report (#25). July 28, 1981.

2.4 The Canadian Mining Industry

2.4.1 Statistical Profile of the Mining Industry

The Canadian mining industry plays a vital and intricate part in Canada's economy. In 1980, mineral and coal production accounted for 4.5% of the Gross National Product (GNP), and was valued at $13,112,000,000.

The respective shares of metallic minerals, non-metallic minerals, and coal is best illustrated in Figure 5. A more detailed breakdown of Canada's (1980) mineral production is in Table II. Note that roughly 85% of Canadian minerals produced are found in hardrock.

From coast to coast, there are approximately 260 mineral mines, 16 smelters, 15 refineries, and 20 coal mines.

TABLE II

MINERAL PRODUCTION OF CANADA, 1980

METALIC MINERALS*	$ x 10^6	UNITS	RANK IN WORLD PRODUCTION
COPPER	1,856	708,416 KG	4
IRON ORE	1,723	50,866 MT	7
NICKEL	1,679	194,947 KG	2
GOLD	1,020	48,284 GM	3
ZINC	860	894,575 KG	1
SILVER	818	1,037 KG	5
URANIUM	638	6,368 KG	2
MOLYBDENUM	315	12,198 KG	2
LEAD	299	273,833 KG	4
TOTAL	9,208		
NON-METALLIC MINERALS			
POTASH	986	7,523 MT	2
ASBESTOS	642	1,335 MT	2
SULPHUR (ELEMENTAL)	414	7,403 MT	3
SALT	126	7,029 MT	7
ALL OTHERS (+)	294	12,312 MT	-
TOTAL	2,462		
FUELS			
PETROLEUM	9.098	84,198 CM	-
NATURAL GAS	6,692	84,402 CM(x 10^3)	-
NATURAL GAS BY PRODUCTS	1,741	18,738 CM	-
COAL	946	36,500 MT	N.A.
TOTAL	18,477		
STRUCTURAL MATERIALS			
TOTAL	1,725		

+ TITANIUM DIOXIDE, GYPSUM, PEAT, QUARTZ, SODIUM SULPHATE, SULPHUR IN SMELTER GAS, NEPHELINE SYENITE

* ALL ARE HARD ROCK MINING

SOURCE: STATISTICS CANADA - CATALOG 26-202 - CANADA'S MINERAL PRODUCTION PRELIMINARY ESTIMATES

FIGURE 5
DISTRIBUTION OF CANADIAN MINERAL PRODUCTS

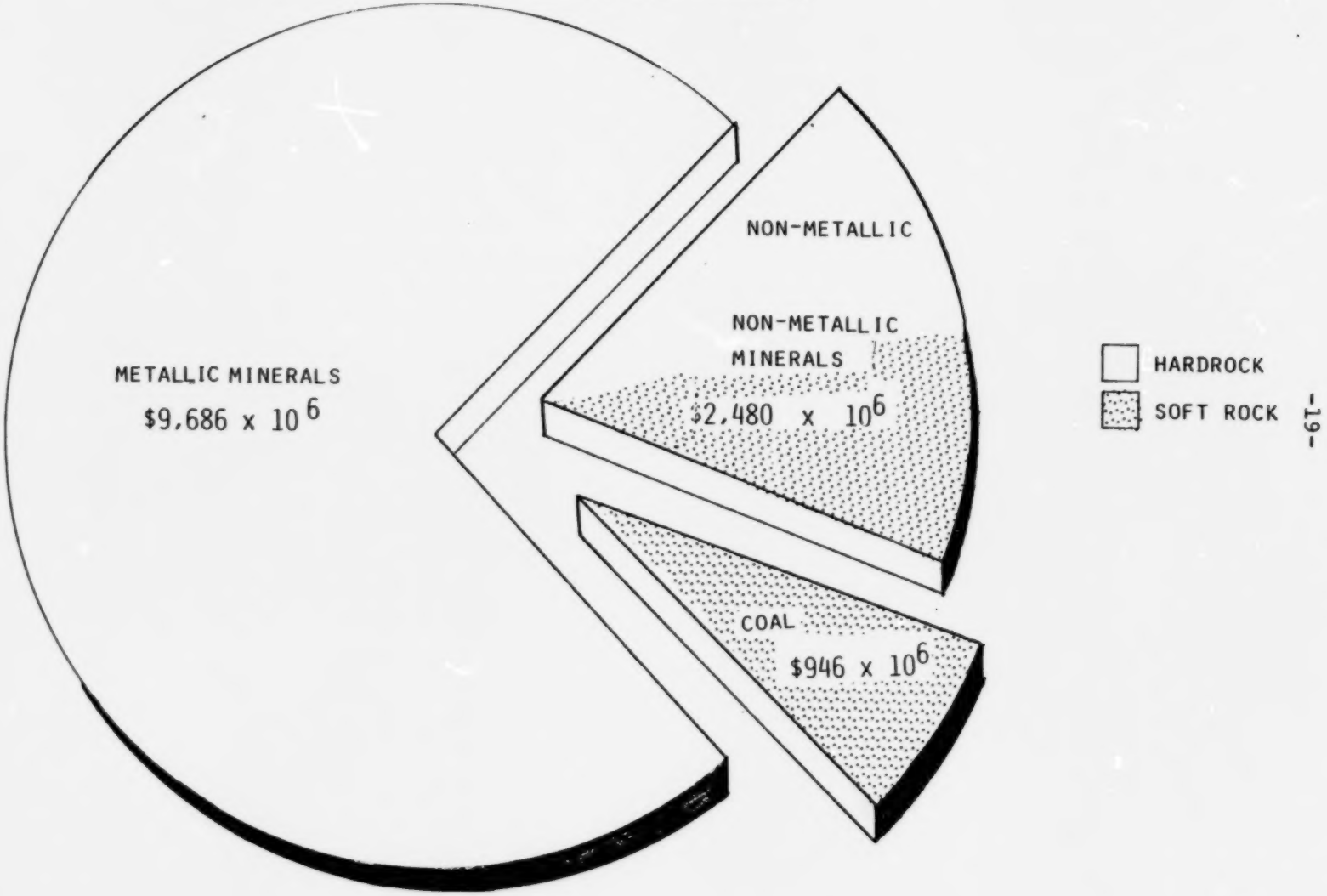


Figure 6 breaks down the mineral mines by size and mining method. United States data is included to provide a comparison between the world's leading nation, the United States, and Canada, which ranks third. (Russia ranks second.)

As a result of the Canadian distribution of mines, this analysis focuses on hardrock underground mining. However, all mine types are overviewed, including:

- metal and non-metallic
  - open pit
  - underground
- coal
- ocean

2.4.2 Mining Machinery Technologies

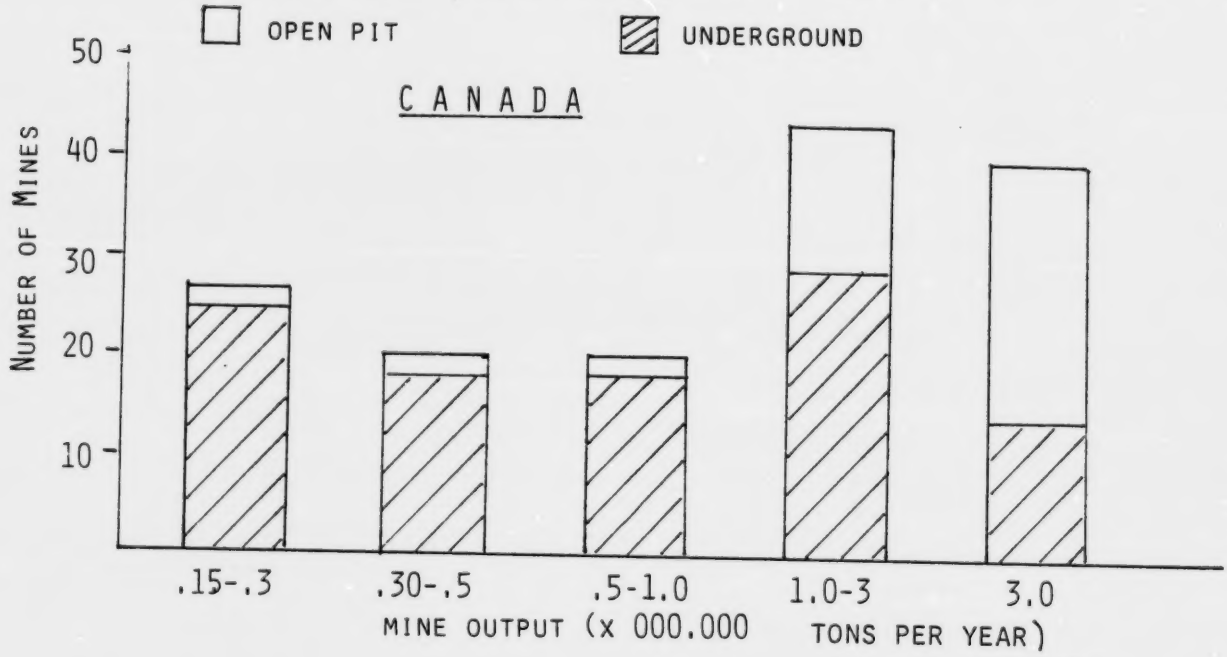
A wide range of technologies and configurations of machinery are utilized in mines across Canada. The technology and machinery utilized is dependent on a multiplicity of variables including:

- ground conditions
- ore orientation and location
- ore concentration
- age of mine
- labour availability
- company experience
- investment and operating capital availability
- many other factors

In 1980, the Canadian mining industry spent $1,200 million on machinery, equipment, and parts. Table III is a synopsis of the Canadian mining machinery market.

FIGURE 6

THE NO. OF CANADIAN AND U.S. MINES*
PRODUCING MORE THAN 150,000 TONNES OF ORE PER YEAR (1981)
(*EXCLUDES COAL AND OIL SHALE MINES)



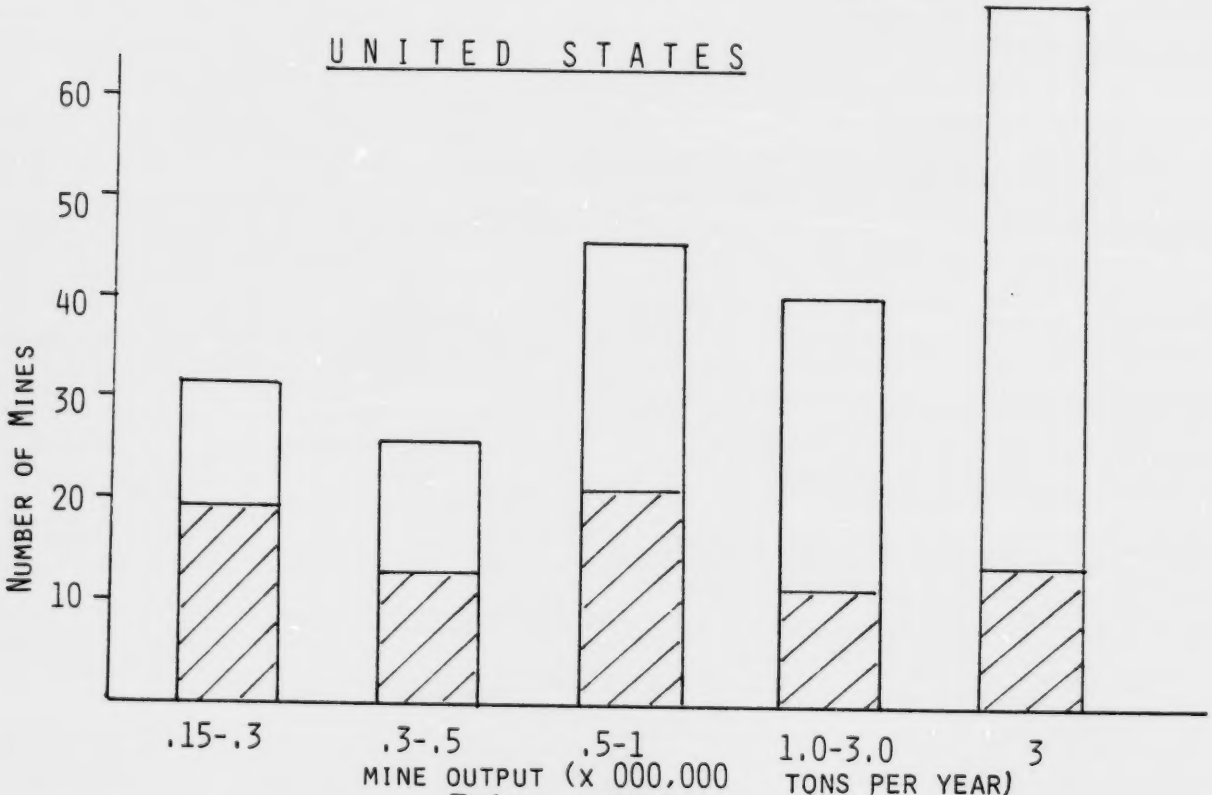


TABLE III

SYNOPSIS OF THE CANADIAN MINING MACHINERY MARKET

CATEGORY	1977	1978	1980
		($ MILLIONS)	
SPECIALIZED MINING MACHINERY AND EQUIPMENT*	-	289	-
ALL MINING MACHINERY, EQUIPMENT AND PARTS, INCLUDING GENERAL PURPOSE MACHINERY**	900	717	1,200
TOTAL CAPITAL AND REPAIR EXPENDITURES ON MACHINERY AND EQUIPMENT, INCLUDING MAINTENANCE SERVICES***	1,400	1,200	1,900
TOTAL CAPITAL AND REPAIR EXPENDITURES	2,300	1,800	3,200

COMPARISONS -

TOTAL U.S. MARKET FOR MINING EQUIPMENT WAS $U.S. 3,820 MILLION (NEARLY FIVE TIMES AS LARGE IN 1977).

NOTE: ALL THESE CATEGORIES EXCLUDE EXPENDITURES MADE BY THE PRIMARY METAL SECTOR BUT CONTAIN A SIGNIFICANT AMOUNT OF SMELTING AND REFINING EXPENDITURES MADE BY INTEGRATED MINING COMPANIES.

* ITC ESTIMATE.

** EMR ESTIMATE, REMOVING THE 60% LABOUR CONTENT FROM THE REPAIR EXPENDITURE EVALUATION FOR 1977, 1978, AND 1980

***STATISTICS CANADA 61-205

Source: Mineral Policy, EMR, 1982

It is beyond the scope of this report to detail all the available equipment technologies. The primary equipment categories covered by this report are summarized below:

Open Pit
- Drilling
- Blasting
- Digging
- Loading
- Haulage
- Crushing

Underground
- Shaft sinking
- Drifting
- Raising
- Drilling
- Ore removal
- Ground conditioning.

The potential for robotics is discussed in relation to the following underground mining technologies:

- room and pillar
- cut and fill
- longwall
- blasthole stoping
- shrinkage stoping
- vertical crater retreat
- sublevel and block caving

3.0 MINING INDUSTRY PERCEPTIONS OF ROBOTICS

The initial reaction received from the mining industry to the concept of robotics in mining is either a chuckle...or silence.

> "We only use live robots"
>
> Adams Mine

> "If I suggested a robot for underground operations, they would send me to a nut house!"
>
> Consolidated Coal

The term "Robot" has a negative connotation when used in a discussion with the mining community. Most miners associate a robot with a science fiction character such as R2D2, or a General Motors spot-welding robot.

General knowledge about robots and robotics has come from reading magazine and newspaper articles. It is the rare individual that has gone beyond this stage and has actively tried to obtain more information.

The majority of respondents consider the use of robotics in mines as being totally unrealistic. The concept of mining using extensive remote control, robotics, and automation, is thought to be very futuristic.

> "People who gaze into the crystal ball and predict the future tend to end up eating glass."
>
> Noranda

The immediate reasons cited by miners as to why robotics are unsuitable for the mine can be counterbalanced by statements received by the same individuals as they begin to think about robotic potential:

Immediate Miner Objections to Robots	Positive Reaction Upon Thinking of Robotic Potential
No Two Ore Bodies The Same	Limited Number of Mining Methods
No Repetitive Operations	Three or Four Phase Production Cycle
Not a Continuous Operation	Certain Processes Are Bottle necks That Could Be Eliminated By More Sophisticated and Integrated Machinery
Environment Too Harsh For a Robot	Environment Too Harsh For People
Lack of Skilled Maintenance Personnel	There always Exists the Potential for Equipment Damage Due to Operator Error.

There is a general laissez faire attitude which tends to let someone else develop new machinery or technology. Then after it is proven, they might try it in their mine.

> "A major problem is the tendency to consider mining more of an art than a science."
> Joy Manufacturing

> "At the rate new innovation is now entering the mine, there will be no changes in current methods."
> M I T

None of the Canadian companies felt they were involved in any true robotic application. However, all the major mining firms are working on the first stages of robotics/remote control. For example:

INCO - pricing the costs of developing an automated drill jumbo

FALCONBRIDGE - automated large diameter blasthole drilling

KIDD CREEK - 'robotized' raise borer

NORANDA - portable crushers
- remote control loaders

COMINCO - have robots in their refinery plant

Furthermore, as discussions with the mine representatives progressed, and they become more familiar with the concept of robotics, many were capable of suggesting areas of robotic potential. These suggestions are listed below so as to demonstrate the array of potential ideas from an initial response:

"Robots could blast chunks in the muck pile. Very dangerous since there is no ground support."

Falconbridge East

"Robot to change LHD tires since a mine can change up to 30 tires per day."

Amax

"Raise borers or tunnel boring machines may have robotic applications in conjunction with laser guidance."

Asbestos Corp.

"There are robotic applications in the mucking out and ore removal stages."

Atlas Copco

"There is potential for a robot to find trapped miners"

Canadian Mineservices

There are many potential applications of robotics; jacklegs, mucking out, scaling, roof bolting, rail laying, shotcreting, slushing, testing, air quality, installing timbers, following ore veins, clearing ore passes, material handling."

Colorado School of Mining

"Jumbo drills are set up to be robotic."

GCA/Par Systems Corp.

"The charging of holes could easily be robotized."

INCO

"The Hagg loader has potential for robotics."

Copper Cliff Mines

"It may be a number of years, but eventually you will have a continuous rock breaker at the face, a Hagg loader, a portable grinder and ore sorter all feeding a conveyor to the surface on a continuous basis."

Copper Cliff Mines

"Shotcreting is a perfect robot application. It would have flow rate control and a uniform arc."

Copper Cliff Mines

"You could have a machine programmed to recognize drill holes and place the dynamite."

Jarvis Clark

"A robotic indian snake trick using a rubber hose with a hand and gripping motion could take explosives up to unblock an ore pass."

Kidd Creek

"A small robotic application would be the withdrawal of drill rod lengths to change diamond bits."

Longyear Company

"There is the possibility of a completely remote controlled continuous coal miner."

M I T

"Might have a robot to pull the pillars from room and pillar mining."

Colorado Mining Research Institute

-:-:-:-:-:-:-:-:-:-:-:-:-:-:-:-

This analysis indicates that there are many areas of applicability for robotics in the mining industry. The bottleneck in applying these technologies to mining problems is not so much in the cost or availability of the hardware, but instead, in the imagination and ability of engineers to provide the applications.

4.0 ROBOTICS AND REMOTE CONTROL IN CANADIAN MINING

4.1 Existing and Future Scenarios

According to the strictest definitions of robotics and remote control, there is currently no penetration of robotics into Canadian mining and only limited usage of remote control.

However, the previously mentioned overlapping of technology terminology creates a fogginess as to the actual impact of robotics and remote control. This situation is best illustrated by the following quote:

> "An automatic rockbolter and carousel currently exist. Remote control added to the machine provides mobility, and supervision from a safe location. By adding programming with an onboard controller or microprocessor, it becomes a robot."
>
> INCO

The situation is further complicated since there is both the robotic potential for existing equipment and for yet-to-be developed technologies.

Mining involves a sequence of operations which are interdependent. Improvements of mining techniques to date have largely been modifications of conventional drill blast methods and equipment. The introduction of LHD equipment, high performance drills and jumbos, improved explosives and blasting practices, together with new mining systems such as longhole sublevel caving, trackless mechanized cut and fill, under-cut and fill and large blast hole, open stope methods have substantially improved the economies of today's mine.

However, the optimal full implementation of robotics will ultimately be dependent upon an integrated network of fully automated equipment. The full implementation of mining robotics will be slowed down as long as the automation is considered as detached sequences versus an integrated smooth running system.

The implementation of robotics is a gradual process whereby a portion of a job function is taken over by a robot. Then, another portion of the job becomes open to robotics, or the process is modified so that it is more robot applicable. Eventually the entire system becomes integrated. This is what is being experienced in the manufacturing environment.

Therefore, this analysis considers both the existing and short term robotization of operational mining machinery and the longer term potential for integrated robotic/automatic/-continuous systems.

Existing and future robotics/remote control potential is discussed in the following sections under these major headings:

- Underground
- Open Pit
- Ocean

Table IV summarizes the areas of potential for mining robotics as expressed by the Canadian mining industry.

The analysis of mining robotics potential is based on intensive field interviews with miners and equipment suppliers. Many of the suggestions have no prerequisites and would require extensive research, field testing and market and viability analysis.

TABLE IV

SUMMARIZATION OF MINING ROBOTIC AREAS OF POTENTIAL AS EXPRESSED BY THE CANADIAN MINING INDUSTRY

GENERAL ACTIVITY	SPECIFIC EQUIPMENT APPLICATION	AREAS OF HIGH RESEARCH INTEREST
Drilling	Longhole/DTH	- manipulation of drill rods
		- programmed drill patterns and sequences
		- remote control
	Drill Jumbos	- programmed drill patterns
		- parallel drilling
		- remote control
		- bootleg sensing
Explosives Handling	Charging	- Preprogram charging of recognized drill pattern
		- automatic ANFO flow sensing
		- remote control
	Deactivation	- basic design
Ore Removal	L H D	- centralized remote control
		- vision systems for longer operating distances
	Gathering Arm Loaders	- remote control Hagg type loader for hardrock
		- sensor development
		- integrated systems research
	Train Haulage	- further development of remote control above ground
		- computerized sequencing
	Automatic Guided Vehicle Systems	- refinement of sensor coils
Ground Conditioning	Scaling	- mechanization and eventual remote control
		- pressure, vision and audio sensor development

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GENERAL ACTIVITY	SPECIFIC EQUIPMENT APPLICATION	AREAS OF HIGH RESEARCH INTEREST
Ground Conditioning (continued)	Rockbolter	- following preset drill pattern
		- rock formation analysis
		- simultaneous wire mesh installation
	Shotcrete	- ability to judge work surface and uniformity of mixture
Raise Boring		- functional laser guidance systems that are programmable
		- complete automation
		- flexible machine for a variety of ground conditions
Continuous Miner		- development of hardrock applicability
		- more effective impactors
		- automation of flexible ground support and in stope handling systems
Miscellaneous	Draw Point Blockage	- inexpensive remote system for identifying block and dynamiting
	Pillar Removal	- robotized pillar miner for after mine completion
	Sampling Robot	- development of mobile gas sensor
Futuristic Underground Robotics	Telechirics	- centralized remote control of mining machinery
		- long distance remote control
	Continuous	- continuous mechanical robotic mining systems for all rock conditions free of direct human control
Open Pit	Blasthole Drills	- carousel automation
		- programmable operating sequences
	Mine Trucks	- automatic driverless control
	Loaders, Trucks	- centralized remote control
Ocean Mining	Robot subs	- manipulator arms
		- vision sensors
	Crawler rigs	- monitoring systems for remote control operation

4.2 Robotics Potential in Underground Mining

4.2.1 General

Most mine engineers agree that more mines will go underground in the future. Firstly, the major ore bodies that are being found are becoming deeper and deeper, with many of the surface-close ores already mined. Secondly, environmentalists are becoming increasingly successful in the limitation of the deterioration of the environment often caused by open pit mining. The open pit mines have achieved very high productivities using giant equipment. Therefore, techniques underground will necessarily have to be automated in order to maintain productivity and price structures.

This section discusses underground mining robotic/remote control developments under the following headings:

4.2.2 Drilling
4.2.3 Explosives Handling
4.2.4 Ore Removal
4.2.5 Ground Conditioning
4.2.6 Raise Boring and Mini-borers
4.2.7 Continuous Miner
4.2.8 Miscellaneous
4.2.9 Future Robotic Directions

4.2.2 Robotic Applications to Drilling

There are two primary areas of potential in drilling. These are with the

- longhole and/or Down The Hole (DTH) drills
- jumbo drills

4.2.2.1 Longhole and/or DTH Drills

The drilling of holes deep into the ground requires using a series of drill rods. The steps, in simplistic terms are: drilling one rod depth, then screwing the next rod on and drilling another length. When removing the drill rods, the exact opposite takes place.

The potential robotic application is in the manipulation of the drill rods. The machine would be able to disengage from the current rod, pick up a new rod, connect it, drill, and repeat the cycle.

This application is especially suited to where large diameter, heavy drill rods are being used, or in areas where there is restricted head room.

There are machines available on the market with rotating rod carousels or rod handlers. Butthere are only so many rods that can be fitted on a carousel, and they are restricted by length and weight. The carousel does not solve the problem of taking the rods out of the ground.

4.2.2.2 Underground Drill Jumbos

To date, the computer controlled drill has been primarily applied to underground civil construction work.

Short term trends in computerized drilling include:

1) automatic drilling without supervision
2) optimization of drilling parameters
3) automatic monitoring.

The Norwegian engineering and contracting company, Ingenior Thor Furuholmen, has started a development program for automating tunnel drilling rigs. At the present time the company's developments include drilling more than half a million metres of 45 mm holes using a microprocessor controlled drilling jumbo. The latest of several versions are equipped and programmed for automatic and precise drilling of complete rounds according to predetermined drilling plans defined by fixed coordinates.

In the automatic mode, the control system moves the boom to the programmed position for drilling a hole according to a programmed drilling plan. Then the feed rail is moved towards the rock and drilling is started, entering the drill bit smoothly, so that no side-sliding occurs. After the drilling is controlled to programmed depth, the drill is returned and the boom is automatically moved to the next hole position and the procedure is repeated. A programmed drilling plan is displayed so the operator can follow the progress of the drilling at all times. Future developments envisaged for drilling include automatic drilling without supervision and automatic monitoring and indications of equipment failure.

A drifting production jumbo potentially can be designed to drill the rock face following a specified pattern.

The underlying problems are:

- each rock face is different, although in certain cases relatively repetitive;

- each consecutive rock face must be drilled with holes slightly further apart and angled outwards to produce a drift or stope;

- rock conditions and ore direction may change very quickly;

- bootlegs (holes with leftover explosives from the previous blast) must be flushed out.

There are ways around these problems. For instance, a set of drill patterns could be developed and each one placed on an individual tape as is typical of existing NC operations in manufacturing. The applicable drill pattern would be placed into the machine and read. By changing the tape, the drill pattern would change. In cases where it is a unique pattern, the machine could either recognize and read the paint on the rock face, or be shown the pattern through a "walk through" learning process.

Consecutive usage of the same drill pattern could activate an additional loop which informs the machine to shift the drill holes.

The problem of bootjacks may require something in the explosive that can be sensed by the machine, or through better charging and blasting techniques.

This robotized drill jumbo would have the advantage of freeing up the operator or having one operator controlling several production units.

4.2.3 Explosives Handling

Time and labour consumed by charging and blasting is a major cost factor affecting the overall economic operation of a mine.

The areas of most significant robotics/remote control potential are:

- charging
- deactivation

4.2.3.1 Charging

Installed in the Strassa mine in Sweden, is a fully mechanized charging system for charging explosives up to 40 mm diameter in prepacked cartridges. Access to the boreholes is via a telescopic boom which carries a flexible trunk. The hose feeder, mounted on the boom, is pneumatically operated and hose speed can be accurately adjusted both when charging and when feeding the hose to the bottom of the borehole. The operations are controlled by a single miner via a portable remote control panel.

Further robotization of this machine could involve:

- Preprogrammed charging of a recognized drill pattern

- Automatic sensing of the ANFO flow rate thereby providing consistent charges.

The VCR mining method requires bulk loading of explosives into the large diameter blastholes. Currently, this is a manual and labour intensive operation.

Bulkloading involves using a sinker, placing a specified amount of explosive, then a spacer, e.g., 12' of sand or gravel, more explosive, another spacer and continuing in this manner until the hole is filled. Delayed sequencing of the explosive ensures proper blasting.

Contacts indicated that the next logical step is the containerization of the explosives, delay sequencing and then remote control/robotic loading of the blastholes.

4.2.3.2 Deactivation

The failure of a charge to detonate becomes a very serious safety hazard.

Contacts indicated that a remote controlled and/or robotic machine could potentially be used in such a situation for defusing or redetonating the area. There is no such equipment available to date.

4.2.4 Ore Removal

Materials handling is a major component of effort and costs in underground mines. It was apparent that the main focus of the contacts was on the automation of existing systems. Individual requirements for handling of equipment and supplies was generally considered so site specific that robotics was not considered to offer any potential. It was felt in the area of supplies movement that the design of mine shafts and stopes would slowly evolve to adapt to automated systems resulting in improved material handling and less disassembly and reassembly of equipment.

The areas of greatest interest relative to robotics/-remote control for ore removal are:

FIGURE 7

REMOTE CONTROLLED L H D

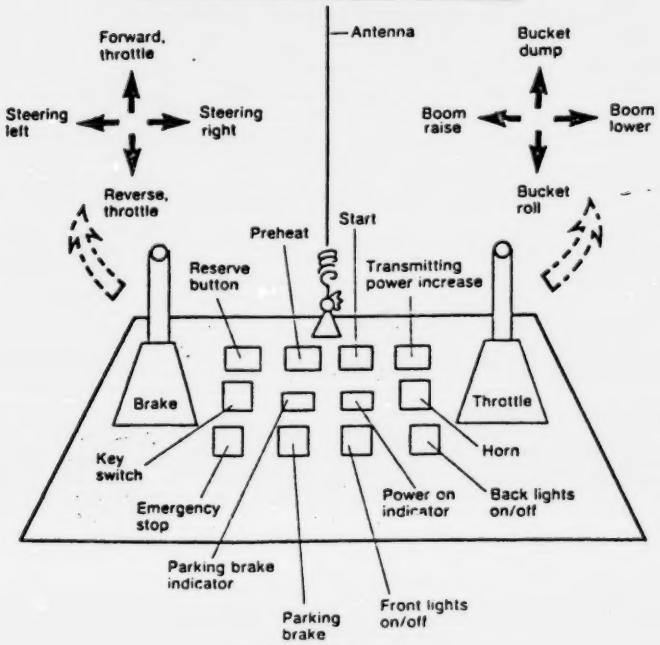
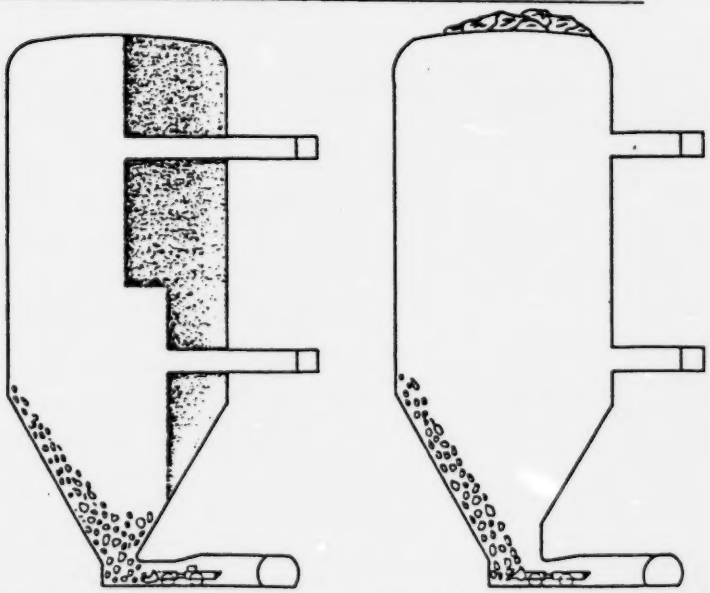


FIGURE 8

REMOTE CONTROLLED L H D FOR UNSAFE AREAS



Normal production loading in sublevel stope. The ore can be safely loaded from cross cuts.

Because the loading cross cuts wear, the loader must work in the big open stope to get it empty loaded. Remote controlled loader is used here.

- LHD vehicles
- Gathering arm loaders
- Remote and automatic trains
- Automatic Guided Vehicle Systems

4.2.4.1 Remote Controlled LHD Vehicles

The main components of the remote control LHD system are (Figure 7).

- a microprocessor based data transmission system
- transmitter/receiver
- receiver security logic
- remote control panel
- control equipment on the LHD

The maximum operating distance is not a function of the equipment, but is governed solely by the unobstructed distance that the operator can see. In the future, it may be possible to control the loading operations in a certain area from one central control point using remote controlled loaders, cameras and monitors. AECL has successfully been using cameras in a nuclear setting. Ocean-miner subs use cameras in deep sea water.

Remote controlled LHD was developed to increase the productivity and safety of large sublevel stoping mines. Under normal conditions, all loading from the sublevel stopes can be carried out by manually operated LHDs. Toward the end of the stopes life, the loading crosscuts become shortened making it

unsafe to load the ore in conventional LHDs (Figure 8). The use of remote control LHDs allows the mine to extract the remaining ore, without sending a man into an unconditioned area.

The implementation of the remote control concept at the Falconbridge Lockerby Mine in Sudbury, is considered to be highly successful. The Lockerby mine reports the following impact the remote LHD had on its larger diameter blast hole stoping mining operation:

- Increased recoverable reserves with expected increase in the life of the mine.

- Substantial increase in revenue because ore that would be left now returns an immediate revenue.

- Decreased development expenditures and development time, as a result of reduced ground conditioning at the loading draw points in the stope.

- Because of the three preceding items, some marginal mineral deposit becomes economic to the mine.

- Solving and simplifying some mining problems reduced stoping costs.

- Reduced employee exposure to potential hazards.

Canadian mines, including Noranda, INCO, and Falconbridge, are using remote controlled LHDs routinely in their mines. It is estimated that there are over 25 radio controlled LHDs operating in Canada.

4.2.4.2 Gathering Arm Loaders

The gathering arm loader loads continuously and is used in conjunction with the shuttle trains, conveyors or truck systems. The Hagg loader, utilizing an overhand system, has begun to be recognized in hardrock mining. This type of loader lends itself to remote operations.

It has been suggested that a remote controlled gathering armloader, with a hydraulic rock hammer, could be used in hardrock mining. Logic would be required to measure the rock size and determine if it needs to be reduced by using a hammer. The sensors read geological, physical size, chemical, weight, and other clues.

One example of electronic ore sorting from Australia, involves the movement of uranium ore lumps on an endless belt, passing over scintillometers which measure the amount of uranium in the ore. As the ore comes off the belt, each lump is optically measured with a strip light source from beneath the belt. The processor determines whether the lump size is within acceptable limits. While the lump is still in the air, coming off the belt, it is sorted. The processor feeds data to a compressed air valve system that fires air at the lumps, moving each to the desired conveyor.

4.2.4.3 Automated Train Haulage

Remote controlled and automated train haulage technology is available.

A typical automated train haulage system consists of electric tolley thyrister controlled locomotives, mine cars, remotely operated loading stations, automatic unloading stations, and a centralized computer control center.

A driverless train is also being developed by a number of Japanese companies including Tokyo Car Mfg. and Nippon.

4.2.4.4 Automatic Guided Vehicle Systems

The basis for automatic guided vehicle systems (AGVS) is a guidepath set up by the electromagnetic field for a continuous conductor, embedded in the floor. A sensor coil onboard the vehicle detects the guidance signal and establishes the path. Any deviation from the guidepath proportionately activates motors to position, steer, or drive wheels to follow the path. Other guidepath methods include painted lines, tape and flurorescent chemicals.

The AVGS systems have had only limited success in mining markets as a result of the harsh mine environment.

4.2.5 Ground Conditioning

Areas for robotic potential in ground conditioning tasks include:

- Scaling
- Rock Bolting
- Shotcreting
- Backfilling.

4.2.5.1 Scaling

To date, there has not been complete mechanization of the scaling process. Both hydraulic rotated tooth and hydraulic and/or pneumatic impactors are available. All operations are very operator dependent.

Scaling is one of the most intriguing potential robotic applications in mining. A scaling robot requires considerable developmental work.

The robot would have to be able to scan the back/ceiling, judge where the faults lie in the rock, and pry loose any rock that might fall.

A great portion of scaling is based on the individual "feel" of the miner. Robotic application would require sophisticated pressure, audio, and vision sensors.

4.2.5.2 Rock Bolter

Mechanized rock bolters are available.

A fully mechanized rock bolter is comprised of:

- a drilling unit
- a charging unit (resin/grout)
- a carousel of 4-12 bolts
- a bolt insertion and setting unit

Currently, the operator controls each phase remotely from a control panel. Alternatively the operator positions the boom, and the machine automatically undertakes the remaining operations

Linden-Alimak, for example, has developed a roof-bolting jumbo. The machine drills the hole for the bolt, then retracts the drill while leaving the guide in place so that the resin cartridge can be inserted into the hole via a tube. Another arm then places the roof bolt.

In order for the rock bolter to become a "robot", it must be programmable. This may involve following a preset drill pattern. This task is more complex than it sounds since

discrepancies are common between the stated pattern, e.g., 4' x 4', and the actual installed pattern. This is a result of the non-uniform roof formations.

The robot would also have to be able to either pick up another carousel of roof bolts, or be able to continuously feed bolts into the machine or hole. This could be done by a manipulator arm.

A further step would be to have the same machine or a separate one installing the wire mesh. The advantage to using one machine is that its memory would know where it had installed the roof bolt to which the mesh is to be attached.

The United States Bureau of Mines has developed two new machines for use in room and pillar coal mining. These roof support systems for retreat mining allow the recovery of the coal pillars without endangering the operator's life.

The Mobile Roof Support (MRS) is battery operated and remotely controlled. Designed to be on the mine side of the continuous miner during pillar removal, the MRS retreats with the miner as fenders are extracted. Four jacks, two on the body, and two at the end of hinged arms, extend to form columns between the mine floor and roof. Alternating movement and extension of the hydraulic jacks allow the machine to "walk" out of the area.

The Remote Breaker Prop (RBP), a remotely-controlled walking support system, is auxiliary-powered from the MRS.

4.2.5.3 Shotcreting (cement mixtures)

Applying shotcrete is an area suggested by several contacts as offering good robotic potential.

Shotcrete is sprayed onto the walls of a drift, lunchroom, mechanics work area, or anywhere in an underground mine that needs permanent rock finish.

A hybrid between a remote control shotcreting machine and a paint spraying robot can be envisaged. The most difficult task for the robot would be judging the rock surface and putting on a uniform mixture.

4.2.5.4 Backfilling

Backfilling is the replacement of material, e.g., shotcrete, tailings, sand, etc., into the excavated areas. Backfilling is not restricted to any one type of mine or mining method. Instead, it is a function of ground conditions, and size of the cavity as to whether backfill is used.

The backfilling of a slurry solution could be performed by a robot. This robot would be very similar to a shotcreting robot.

The bulk mining methods, such as Vertical Crater Retreat Mining, especially lend themselves towards a backfilling robot. A robot appears to suit this application because of the length of filling time, repetitive nature of filling large cavities, and the subsequent labour requirements.

4.2.6 Raise Boring and Mini Borers

The raise borer is another machine which is in the grey area between robotics and straight automation.

Raise borers and tunnel borers can be purchased with options such as a laser sighting unit. The function of the laser system, while not a true guidance system, is to produce a reference so the machine can be lined up.

A Canadian mining company is developing a program that, when used with the laser system, will result in an automated raise borer.

Additional R&D work is required to produce a machine that can be used in more varied ground conditions. In addition, there is still manual labour in starting the drilling and attaching the reaming heads. Drilling at angles greater than 55 degrees from the vertical is another problem.

4.2.7 Continuous/Longwall Miner

Coal mining is perhaps the most mechanized of mining techniques. Enormous advances have been made in the mechanization of longwall mining; particularly the rotary drum shearer, the armoured chain conveyor, and the advancing roof support. Advances have been made in the coal cutting process where a sensor detects when the cutter is a few centimetres below the top of the seam and is controlled automatically to follow the upper boundary but leave in a firm coal roof.

Mechanized longwall coal extraction systems involve automatic steering systems for fixed and ranging drum shearers. Recent guidance systems have been comprised of natural radiation gamma sensors, roof height sensors, tilt and ranging arm elevation transducers, machine health transducers, monitoring and control section with microcomputers and a data transmission system. Future R & D work involves the extension of the guidance systems onto other types of coal face machines such as the buttock shearer and conveyor mounted trepanner.

The Massachusetts Institute of Technology is working on a remote controlled coal mining machine that can be operated from a long distance unlike most current machines which only remove the operator a short distance. The machine has communications, sensors, and a vision system. The system will probably drive a four foot heading thereby potentially eliminating the need for roof bolting and scaling due to a lower surface area.

Continuous miners are primarily used in coal mines and soft minerals such as potash, salt, and low grade iron ore. They have not been applied to hardrock metal mining because of cutting tip limitations.

Two types of mechanized underground mining machines have been developed in past years. Both types of machines were developed for mining minerals which are in "soft" rock. They are systems utilizing chain-driven shears, such as longwall mining systems, and rotary boring systems, common to potash and coal mining.

The Anaconda Company developed a rock picker for cut and fill mining of deep veins in Butte, Montana. The mechanical rock pick is essentially a boom—mounted hydraulic impactor. Tests of this equipment in the Kelley Mine, Butte, demonstrated:

- An upgraded value of ore taken;
- Improved ground conditions requiring fewer work bolts;
- Reduction in scaling requirements.

Further development work would be required to fully automate and robotize this equipment in the areas of:

- more effective impactors, manipulators, booms

- complementary ground support and in-stope ore handling systems.

Cominco's Pine Point mine had experimented with mining their flat lead zinc ore using a room and pillar method with a roadheader. The roadheader is a British ripper type heading machine normally used for driving roadways in coal mines. The ore is broken from the face by its rotating head, which is equipped with tungsten carbide-tipped bits, gathered by a flight conveyor. Further development work would be needed in stronger bits and compatible ground control methods.

4.2.8 Miscellaneous Applications

4.2.8.1 Draw Point and Ore Pass Blockage

There is a need for a device that can blast or break-up any rocks that block an ore pass.

When rock(s) jam up, some methods for unblocking may include: using high water pressure; placing explosives on a stick and try to blast the rock; or drilling down from the drift and then blasting. Most methods require a knowledge of where the blockage is located. Therefore, someone has stuck his head into the ore pass to get a "look".

A robot to take on this task must locate the blockage, apply the explosive, and be inexpensive, since there is a good chance it will be damaged.

One idea that was put forth involved using a Baer Hand and a specially designed hose. The explosive is placed on the hand and by using air pressure, can be manoeuvred up the ore pass.

The Baer hand is a pressure operated gripping device. The fingers are special geometry half bellows which curl and grip when pressurized because of unequal expansion of portions of the unit. Baer hands have no driving mechanism and no moving parts, and therefore require no maintenance and have a relatively low capital cost.

4.2.8.2 Pillar Removal

There is a potential robotic application in the removal of the pillars from the stope. In room and pillar mining, the pillars are either left behind or mined out during the final stages. This can be a very hazardous undertaking.

Robots could potentially be used to go in and mine out the pillars. If the roof collapsed, only the robot would be lost. If it did not collapse, the mining company could potentially gain up to 40% more ore, which was considered lost.

Required is a remote control/robotic system for the removal of this ore. This system is obviously futuristic, yet must be considered since the value of the recovered minerals would be so significant. Contacts were not able to provide further detail on this idea without a lot more background information.

4.2.8.3 Sampling Robots

A sampling robot would be used to monitor levels of methane, carbon monoxide, and other toxic gases. A vision system could be used to detect broken ventillation lines, hydraulic pipelines, and so forth. The mobility of a sampling robot would likely be remotely controlled under current technology capabilities. With the development of more sophisticated vision systems, robots could potentially move totally independently.

There are existing monitoring systems for use in the mine. The major disadvantage of these systems is that the sensors are generally in fixed locations all over the mine thereby requiring extensive communication facilities and wire to link the sensors to the computer.

Robots could potentially add flexibility into the monitoring system. For example, the sampling robot could be sent into areas ahead of the miners. The robot could also, because of its mobility, monitor all the working areas of the mine.

4.2.9 Future Directions of Robotics in Underground Mines

One suggested reason that much of the world's minerals cannot now be economically mined is that there must now be a human accessible working face and a human life support system at the face. This involves daily transport of people from the surface to the face, a ventilation system that removes dust and gases and provides breathing air, space sufficient for people and machine to move and work in, illumination, machine safety, and prevention of rock falls and fires. All of these factors significantly increase the mine's operating expense and thereby decreases the productivity ratio.

The future may see two or more different solutions to the underground mining dilema. Both approaches are at least 20 years away from initial trials, however, from a long term strategy perspective, all futuristic options must be at least peripherally considered. The two more currently favoured robotic/remote scenarios are:

- telechirics

- complete automation/continuous mining.

The ultimate aim of the technology of telechirics is to enable the full coordinated physical skill of a man to be used at the other end of a wire or radio link with scaling up of strength.

The British have been advocates of the telechiric mode of automation. A telechiric system consists of a number of human masters sitting in a control room operating controls and receiving signals connected to an equal number of telechirs.

In the mining context, the ultimate in robotics would be equipment that achieves high production per unit of time or per unit volume of rock using essentially non-cyclic, non-explosive continuous methods. Eliminating the principal constraint imposed by the mining cycle, i.e., drilling, blasting, scaling, timbering, mucking, etc., is the key to the development of true robotics. The cyclical constraint establishes a limit on excavation rates related to the amount of ground that will stand open after a blast long enough for support to be installed. However, the ultimate in continuous mining and/or robotics would be limited only by the capability, capacity, and compatibility of the robotic machines to break the ore, reinforce the ground, and handle the muck simultaneously.

The picture above is painted with a very broad brush and undoubtedly could be hypothetically refined. The point of this discussion is to demonstrate that robotics can be implemented at several stages of a mine's operation.

The short term occurrences of individual machine remote control may lead to individual robotic development. Long

term developments such as telechirics or continuous hardrock mining may be instigated by the short term developments or through new technology developments. For example, there are more novel methods of drilling holes or breaking rock that must be considered, such as those involving thermal fragmentation, the plasma torch, microwave generators, electron beam guns, and ultrasonic drilling. These new technologies may totally change the current direction of mine automation.

The development and direction of underground robotics is ultimately dependent upon a range of financial and environmental factors. These factors are discussed in detail in Section 5.0.

4.3 Robotics Potential in Open Pit Mining

In open pit operations, the last twenty-five years have witnessed the introduction of the use of construction type equipment. The higher productivities realized by this massive equipment has enabled lower grade ores to be mined profitably. The industry now has huge 200 ton trucks, 20 yard shovels, 60 yard drag lines, and large bucket-wheel excavators being used in the open pits.

The open pit mine of today has moved towards a working environment of modern, well lighted, air conditioned equipment and in general has improved the condition of the working place. As a result, the open pit mines are not faced with the same drastic shortage of labour as the underground mines. In the open pit mines, equipment will continue to increase in size as it becomes necessary to move more mine material as lower grade ore is mined.

These two factors of better working environment and large size equipment, reduce the potential impact of robotics in open pit mining.

There are isolated areas where robotics may prove to be useful. For example, the blasthole drills for high speed rotary and downhole drilling are similar in many respects to the underground drills. These drills are currently available with carousels to add or remove drill rods. One could conceivably add intelligence to these drills and provide them with programmed drill areas and self control. However, this is only one small area in open pit mining and is not considered to be a bottleneck in the operations.

There has been limited experimentation with automatic operation of surface mine trucks on the normal cycle between the loading face and the dump station. Automation of these vehicles, to date, has not shown any significant increases in productivity.

The potential exists for remote control of the trucks, shovel loaders, etc. For example, the Erie Mining Company, Minnesota, developed and tested a rugged close-circuit television (CCTV) which monitors loose or lost bucket teeth. Some mines have estimated that annual shovel productivity can be decreased by as much as 5% as a result of lost bucket teeth. The system consists of an optical low light camera with an automatic iris, specifically designed for day and night operation, which controls glare problems, and a monitor which is installed in the shovel cab. The same system integrated with a control network would allow for remote control of the loader. However, the advantage to this is not immediately obvious. Current development work continues towards increasing the efficiency of existing operations.

Bucket wheel and bucket chain excavators are already fairly automated and not dependent on a large number of operators. It is unlikely there are any robotic or remote control operations that would be applicable.

In summary, the reasonably attractive work environment, the gargantuan size of machinery, and the reasonably advanced state of automation work inhibit the applications of robotics and/or remote control to open pit mining. There will only be isolated job activities that are amenable to this level of automation, and given Canada's low ratio of open pit mines, it is believed that the future will not see a dramatic shift in open pit automation.

Surface mining will be with us for some time; however, as more of the metal is removed from the earth's crust, it will probably be necessary to return to more underground mining in Canada. Effort should therefore be directed towards the robotization of the underground mines.

4.4 The Potential For Robotics In Ocean Bed Mining

The seabed has the potential of being the mineral bonanza of the 1990's. The deep sea bed holds large reserves of manganese, nickel, and cobalt. Development is being snared by economic and technological uncertainties, as well as problems over jurisdiction. There is a possibility of artifical stimulation of ocean mining by nations seeking an independent source of nickel without regard to cost, which could result in premature production from the seabed.

There is an element of robotics in some of the interested consortia are proposing. Afternod, a French group of state and private interests, is exploring the possibility of using unmanned shuttles to gather up the potato-like manganese nodules found over large areas of the seabed at depths averaging 5,000 metres.

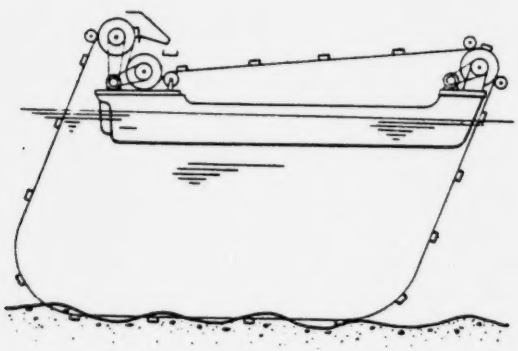
Inco and Sedco each are a 25 percent partner in the Ocean Management Inc. consortium, although they perceive initial production from the seabed may be delayed beyond the 1990s.

The growing family of "robot subs" is divided into four groups. Towed vehicles are powered and controlled via tethers linked to the mother ship. The craft generally are used for high-resolution still photography. Next comes bottom crawlers which may weight more than 100 tons. They too receive communications and power through surface-linked umbilicals but also have on-board motors to control foward and sideward movement. Another class of robot subs also has tethers but can swim free in all directions. These highly manoeuverable craft carry powerful lights, color TV cameras, sonar, and versatile gripper arms. The final group includes the experimental swimming, untethered vehicles. When perfected, these autonomous robots will have both power and programs on board that may be controlled by as yet undeveloped water transmitted communications, perhaps via laser. Most of the robot subs in use today are bottom crawlers and free swimming flyers. Their principal application will be in exploration and ore reserve delineation.

Remote controlled crawler rigs are manufactured in Japan. The equipment continuously dredges underwater mineral deposits. Plural pairs of pulleys are used to scrape up ore via buckets and then circulate the material to the upper deck of the barge. The Japanese are now in the process of adding computer control to the crawler drill.

FIGURE 9

REMOTE CONTROLLED CRAWLER RIG



5.0 FACTORS AFFECTING THE FUTURE OF MINING ROBOTICS

5.1 General

Industry has been swamped with predictions of robot usage. While these are exciting opportunities, little has been said about mining robotics. This section attempts to define the predominant factors affecting the acceptance of mining robots and realistically predict the Canadian situation over the next 20 to 25 years.

The commercial justification for mining robots will be based upon:

5.2 Safety
5.3 Productivity
5.4 Labour
5.5 Mine Uniqueness
5.6 The Economic Climate
5.7 Canadian Mining Level of Innovation
5.8 Robot Technology.

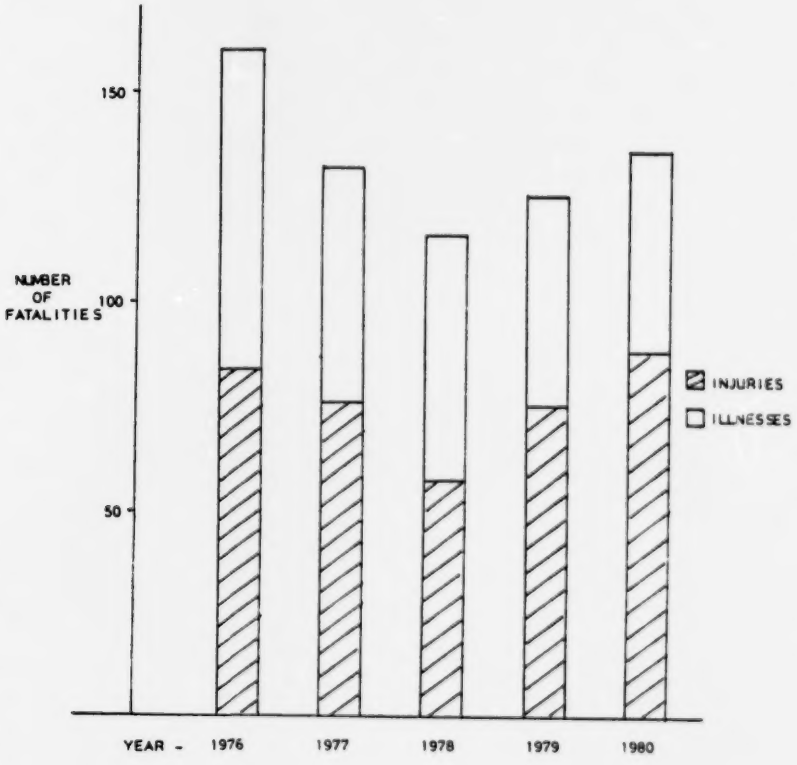
5.2 Safety

Fatalities in Canadian mines are in the magnitude of 100 to 150 per year. Figure 10 shows the number of mine-related deaths.

The frequency of fatalities is approximately nine times that of all other industries. Only forestry and fishing have comparable or higher fatality frequency. Figures 11 and 12 illustrate the percentage of fatalities per 1,000 workers.

FIGURE 10

NUMBER OF FATALITIES IN ALL MINING CATEGORIES



Source: Labour Canada, Canadian Employment Injuries and Occupational Illnesses

FIGURE 11

NUMBER OF FATALITIES IN MINING

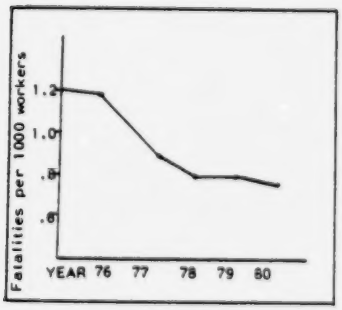
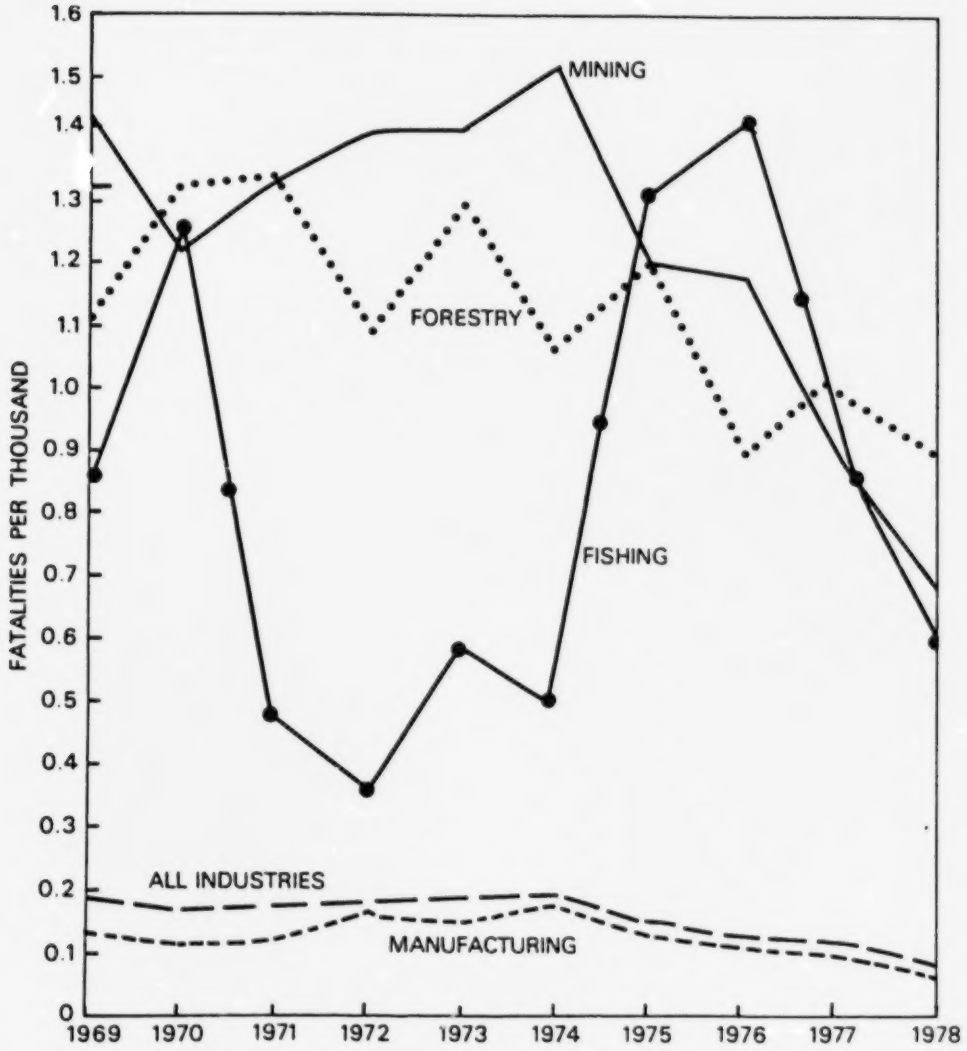


FIGURE 12

INDUSTRIAL FATALITY RATES



Source: Mineral Policy a Discussion Paper, Dec., 1981

As to be expected, the number of deaths varies with the actual work place. Table V shows the frequency of fatalities per work area. Note that a worker has three times the chance of being killed if he works in an underground mine versus an open pit.

TABLE V

FATALITIES BY WORKPLACE

WORK AREA	No. of EMPLOYEES (1974)	FREQUENCY (No. Deaths/1000)
Underground	16,040	.446
Open Pit	1,200	.160
Concentrators, Smelters and Refineries	10,732	.045
Shops and Surface	9,475	.066
TOTAL	37,447	.215

Source: Report of Royal Commission on the Health and Safety of Workers in Mines, Ham Commission, Province of Ontario, 1976

Occupational injuries occur a thousand times more often than actual fatalities. Approximately 9% of the workforce will suffer a time loss accident during the year. Estimates reveal that the injuries result in a loss of 31-1/2 work days per injury. Suffice it to say that direct salary loss is in the magnitude of $90 million . Actual production loss is likely twice this figure.

Mine safety is a major concern to industry, unions, government, and individual workers. Considerable time and expenditure goes into providing a hazard free work environment.

However, as long as there is manual scaling, rock bolting, and charging, there are bound to be accidents. Government regulations and union demands will get increasingly more stringent with regard to safety. Robotics and remote control are one of the strong tools that the mine has in terms of complying with the demands for a safer environment. Safety will be a major instigator in terms of mines adopting remote control, particularly over the next 10 years.

5.3 Productivity

> "The biggest bottleneck is moving men and material down the mine shaft."
>
> Falconbridge East Mine

There is a significant loss in production time just getting people to and from the work site. Up to two hours per person per shift is lost in just getting people from the surface to underground. The total cost to the mining industry is an estimated $18 million per year.

Robotics and remote control eventually will reduce the labour requirement or at least shift the workers so that fewer have to go below ground. The increased productivity for those who now have to travel an additional 2 hours per work day could be as high as 25% more available productive hours.

Machinery and material movement, both into and within a mines, is an expensive, laborious, and time consuming task. Mine automation will eventually result in the design of mine

shafts and stopes that cope with the new technology, resulting in improved material handling and less disassembly and reassembly of equipment.

More productive automated and continuous mines using a high degree of robotics will mean that fewer stopes will be required for any given mine production rate. Fewer stopes means less development, lower ventilation requirements, easier and cheaper servicing, easier and more effective supervision. With less development required for a given production rate, the time required for bringing a new ore body into production is shortened; capital requirements are lowered, and interest payments thereby reduced.

> "Canada will have to do work in developing mining robots, otherwise we will price ourselves out of the market."
>
> Kitsault Operations

5.4 Labour

Labour supply and cost is becoming a chronic problem in Canadian mines. The number of skilled miners is growing smaller. It is increasingly difficult to find men to work underground and in remote locations. Furthermore, the miners want, and it is a reasonable request -- a more comfortable, safe working environment.

Wages have increased 11% annually over the past 6 years (Figure 13). Despite the recessionary times, it can be expected that miners will continue to demand more for their skills and services.

The shortage of skilled labour is always acute when economic times are good. There have been a number of predictions indicating that a severe shortage of miners will occur in the 1990's.

The shortage of skilled labour was very noticeable three years ago. Currently, there is no problem with lack of skilled miners due to recent mine layoffs.

The mining industry has generally had difficulty in obtaining and maintaining highly skilled trades personnel. The working conditions, location of the mines, and competition with other industries inhibit the retention of tradespeople.

Extensive use of robotics will likely reduce the total labour requirement. Though the need for skilled maintenance men would be increased, the requirement for broad mining skills should be reduced.

Given all of the labour problems that face the underground mine, it is impossible to not envisage heading towards technology which will greatly reduce the number of underground workers.

5.5 Mine Uniqueness

The typical metal ore body is irregular in shape, of non-uniform mineral distribution, and of varying thickness.

Geological conditions change as the ore is removed and mining techniques may require modification.

Mines in Canada are in a variety of climates, have dramatically different stope angles and use a range of mining techniques.

These factors are likely the greatest barrier to the immediate implementation of mining robots. Commercial justification requires markets of sufficient size to afford economies of scale.

> "It is hard to say why Canada is not as advanced in their mining equipment...it could be that Canada is too fragmented a market and just not worth it."
>
> Joy Manufacturing

5.6 The Economic Climate

The mining industry is cyclical. It is likely that there will be a drastic reduction in the value of 1982 production, to perhaps as low as $10 billion to $11 billion from last year's record of $15.2 billion.

Unfortunately, tradition has it that when business is slow, R & D is one of the first departments to be disbanded. This attitude over the next several years in combination with a general overall "tightening of purse strings" will tend to inhibit the rate of new robotic mining development.

> "Poor economic conditions inhibit R & D and product innovation."
>
> Gardner Denver

> "Robotics in mining would cost more money than the industry could afford."
>
> Atlas Copco

"Development costs to put a microprocessor on a drill jumbo could not be justified."

Gardner Denver

5.7 The Level Of Innovation In Canadian Mines

"The word primitive to describe mining techniques is not too harsh...I have heard mining techniques called neanderthal."

M I T

The Canadian miner is generally perceived by themselves and others as being very conservative despite the fact that a number of Canadian mines can be considered world technology leaders.

"The biggest difficulty is getting innovative ideas and equipment to be tried by mining companies."

Elmac Corp.

Aside from the conservative nature of the miner, another factor with relation to innovation is just as significant and apparent. There is really no central group of companies spearheading new technology development. The mandate for technology development is generally tossed between the equipment supplier and the mine.

"Robotics requires basic developmental work which the industry does not involve itself with."

Sullivan Mines

"There is lack of communication between mines although it is getting better because of conferences."

Kidd Creek

"Mining companies are very slow in adopting new technology...there is an information barrier."

Kitsault Operations

The reported state of innovation in Canadian mines may present itself as a significant impediment to the development of robotics in the mining environment.

5.8 Robot Technology

Use of robotics in mining will necessitate technological development different from that which is currently underway in manufacturing industries.

Some of the most important technological requirements for mining robotics are:

5.8.1 Sensors
5.8.2 Reliability
5.8.3 Safety
5.8.4 Flexibility
5.8.5 Intelligence

5.8.1 Sensors

The prerequisite for any robotics or even straight automation is the development of accurate, reliable and efficient sensors. The sensors must be able to cope with the mining environment of dust, dirt, and temperature.

There has been a considerable volume of research and development on sensors over the past few decades. However, there is still much work to do. For example, a mobile robot at Pittsburgh's Carnegie-Mellon University, can use a TV sensor to navigate through an obstacle course, but its computer requires so much time to process the complex information that it takes about 15 minutes to move ahead a metre.

There is work being done on developing a robot that can "see" in three dimensions. Existing camera systems provide only two dimensions, therefore, the robot has no depth perception.

A recent development has been a robot that can distinguish the orientation of an object from a bin of identical objects. The robot can then rotate its arm and pick up an object.

The mining environment presents additional problems to any vision system. Coping with the dust and shock waves from an explosion are barriers which must be overcome.

Sensors were one of the most frequently mentioned subjects during the course of the study. It was generally felt that more R & D was needed in this area before remote control and robotics realized their full potential.

5.8.2 Reliability

The reliability of any machine, particularly a sophisticated robot is a major concern to the mining industry. The industry is concerned with:

1) hiring skilled technicians to repair sophisticated robots;

2) cost of maintaining a robot;

3) increased down-time while trouble shooting.

There is no question that many existing robots could not withstand the mining environment. This is another area requiring further technological development before robotics is fully accepted.

5.8.3 Intrinsic Safety

Electrical equipment for use underground or in areas with flammable gases must be designed intrinsically safe.

Intrinsically safe is when there is no risk of a spark setting off an explosion. For instance, a programmable controller must be designed to withstand any internal explosion that is the result of a spark igniting a gas (methane).

Design work would be required to build an intrinsically safe robotic system.

5.8.4 Flexibility/Mobility

Mining is a mobile production factory where the machines must move to the product. Excavated ore is not an amorphous mass, but rather consists of irregular shapes and weights. Flexibility is a primary requirement.

The development of a robot which has mobility is anticipated within the next five years. This advancement of technology will have a significant impact on the robotics industry.

Thermwood Corporation of Indiana is developing a robot that can load tractor trailers. Mobility will be built in as opposed to remote control by an operator.

The mine presents intriguing problems that a robot must contend with. A robot would have to be able to move over rocks, through water and mud, up steep gradients, and avoid any obstacles in its way.

Remote control from greater distances using vision sensors will likely be the precursor to true robotics while development work proceeds on self-mobile robots.

5.8.5 Intelligence

To a large extent, mining decisions are based on the retrieval of past experiences and judgment.

Artificial intelligence involves reasoning, judgment making, and even the capability of learning. Using artificial intelligence technology, a computer can readily sort through signals coming from cameras and other sensors to identify images and sounds. Artificial sight and hearing will be useful in guiding robot arms. The first rudimentary software for robot vision is just now entering the market.

"Mining requires machines that are idiot proof."

Falconbridge

The robotics industry is just on the brink of major advances in programmed intelligence. The mining environment is so harsh and variable that mining robots will require intelligence to cope with the array of different variables.

6.0 PRIORITY AREAS IN THE DEVELOPMENT OF MINING ROBOTS

In selecting the priority development areas, the relevant factors to be considered are the technology phase already attained, the value of the potential contribution of robotics, and the availability of the technical resources necessary.

Automation makes the most sense if it has been preceded by extensive mechanization. There is a progression through stages of the "technology tree" (Section 2.1) from manually performed tasks to automatic and/or robotics control.

Therefore, it is reasonable to initially define those areas which can be immediately developed and progressed rationally through the technology tree.

> "Can't go the straight robotic route before having telechirics."
>
> Carnegie Mellon University

However, in the particular circumstances of mining, the optimal automatic systems may be fundamentally different from those which now exist as in continuous mechanical mining versus the traditional drill and blast technology.

> "We really need a method for eliminating the drill and blast sequence -- need a method of continuous mining."
>
> Falconbridge

Therefore, optimization of the research efforts in individual equipment and application of the results for long term benefit necessitates also researching those areas which now may appear futuristic.

"Putting robots into mines will be a long term and difficult project, that will take at least 20 years."

Cape Breton Development Corp.

Given the above rationale, the following areas are seen as priority research areas in order of importance relative to the development of robotics and remote control. These priorities may differ from mine to mine as a result of the individual perspective. The suggested areas have the widest applicability. The priority list is based on activity need versus any economic justification. Potential markets and manufacturing viability would of course, have to be demonstrated prior to commercial exploitation.

Mining Robotics Priority Development List

I. Short Term Priorities

a) by work activity

- scaling
- rock bolting
- ore removal
- drilling
- all other areas

b) by research activity

- flexible development of existing remote control systems for application to other mining machinery

- development of sensors specific to mining requirements

- design of sturdy robotic equipment to resist the mine environment

- design of mobile robots for rough terrain.

II. Long Term Priorities

- Identification of technologies that may offer continuous operation for Canadian mines.

- Development and test of hardware concepts for continuous mechanical mining of hardrock.

The above priority list is not intended to preclude specific mine projects. The list essentially highlights the cumulative opinions of all industry contacts and the analysis of data collected. Preliminary viability justification should likely be undertaken to develop a priority list based on sound economic rationale.

7.0 THE ROLE OF EMR/CANMET

7.1 Should EMR Become Active In Mining Robotics?

The Financial Post and the Mining Association of Canada estimate that of the 130,000 persons directly employed in mining in 1981, about 8,500 already have lost or will lose their jobs permanently by early 1983. Many more are expected to be on lay-off by late summer and early fall.

There are also thousands of workers in other industries which will be affected. As a primary industry, mining generates employment for about three persons for every job it creates directly.

The future economic growth in Canada is very much dependent on the mining sector. Therefore, investments in this sector must be directed to areas that will increase capacity and productivity and at the same time, improve the working conditions for the mines.

The implementation of robotics and remote control has the potential to increase productivity. Without productivity increases, more jobs will continue to be lost as Canada becomes less competitive in the international mineral markets.

Admittedly, many miners perceive robotics to be a futuristic subject in relation to mining applications. However, failure to react immediately and effectively to all aspects of performance optimization will eventually put Canadian mines in a "catch-up" position. Many of the potentialities of robotics are long term and as a result are beyond the scope and means of the individual mine.

Therefore, the support of mining robotics by EMR can be viewed as a part of the mechanism for maintaining Canada's position and role in the international minerals market.

In a preliminary study of this nature, the industry contacts are never able to fully elaborate concerning implementation details. However, the general consensus of the mining industry is that there needs to be some research into different mining robotic opportunities. Contacts felt that the industry should play the major role, however, it is felt that only through government initiative and support would the companies likely become active in this area.

7.2 A National Mining Robotics Program

An EMR sponsored mining robots program would act as a catalyst towards the development of robot technology. The national program would consist of four subprograms:

1) promote and focus research and development on productivity and safety enhancement through robotics and remote control;

2) ensure that all key players in the Canadian mining industry are kept aware of robotic developments;

3) organize and support a joint effort engaged in developing mining robot applications;

4) encourage primary robot manufacture as a commercial venture.

The following sections detail the activities of each subprogram.

7.3 A Focused Research And Development Effort

7.3.1 Short Term R & D Effort

Specific mining research programs would develop:

- industry standards, i.e., uniform software, electrical and mechanical safety standards, so that efforts in robotic development can be optimized;

- concepts applicable to and directed at the mining industry;

- technology directly applicable to mining activity.

Information on mining robots is at the infancy stage. There are many areas of mining robotics that need to be fully analyzed from a technical and economic viewpoint. This is a task requiring cooperation between government/industry and academic research institutes.

Initial goals for information collection would be:

- detailed conceptualization of specific robotic apparatus;

- forecasting of the technological direction of existing mining activities and the strongest entry point for robotics.

- conceptualization and preliminary research into integrated mine activities to optimize the interrelationship of equiment through automation.

A major functional goal would be the development of specific software and hardware applicable to mining.

In the short term, a major contribution to the development of hardware would be research to establish precise performance criteria for various robotic applications.

Areas for initial concentration include:

- robot accuracy requirements

- sensor development

- application of existing remote control technology

- specific mine access and configuration requirements for mining robots

- development of mobility for robotic machines

- development of grippers and end tools

Software development areas of immediate concern are:

- video information processing

- compatibility of languages with others in mining machinery control

- development of modular safety systems

7.3.2 Long Term R & D Effort

Broad guidelines must be established now with regard to mining system requirements of the future. Important stages of activity include:

- forecasting of future mining technology changes;

- economic prediction of mineral products critical to Canada over the next several decades so as to focus research efforts;

- development of research objectives by identifying the unknowns with regard to the future mining industry.

Planning must be started now for research concepts in the 1980s to be applied prior to 2000.

7.4 Mining Robotics Awareness Program

An awareness program to inform miners of robotic developments is needed simply because the mining industry to date has never been under very great pressure to change and move forward technologically.

The major goals of the awareness program would be:

- interactive discourse between industry leaders;
- relay of development of a "shop window" where new robotic developments could be displayed in action. This could be a developmental site or in different mines throughout the country.
- development of an ongoing data bank of all existing technological information with respect to mining robotics.

7.5 Joint Robotics Developmental Effort/Application House

The existing mining robotics infrastructure is weak because there has been insufficient application demand to support it. Conversely, applications will not proceed quickly unless the infrastructure can be developed.

This infrastructure is comprised of many different elements but its main goal would be to make skilled application engineering people and rationale available to users, so that they can get application benefits.

Application engineering activities are normally financed through the long term benefits of specific projects and require two kinds of R & D activity.

- workshops where new hardwares and procedures can be developed away from the production pressures;

- workplace development so that implications of particular approaches are reasonably established.

These facilities are not available commercially, and academic institutions and the majority of the Canadian mining industry have not generally responded to these needs.

The development of mining robotics calls for close cooperation between mining, electrical, and mechanical engineers, and data and systems analysts, government and the machinery industry. A joint effort by these participants could establish the needs and kind of work is relevant to the mining industry.

The joint mining robotics development group would provide the impetus for:

1) Feasibility studies for:
   - application of new robotic technology
   - mining companies new to robotics

2) Engineering and commissioning of single robots in complex mine applications.

3) Integrated mine system projects where there are no specific spearheading companies.

The range of work undertaken could include;

- consulting for specific mine robotic applications;
- detail design pertinent to mine conditions;
- installation and commissioning;
- design of peripherals;
- software production.

The know-how applied to projects would come principally from the accumulated skills and experience of individuals who would be carefully recruited from a variety of disciplines including people from academia, government, and the mining industry.

The mechanism for coordination of such a joint effort may be through the efforts of a private company so as to establish industrial credibility. Companies that could take an active role might be:

- an offshoot of a mining machinery company;
- an offshoot of an existing consulting company practicing mining/manufacturing engineering

- an offshoot of an existing engineering software house

- a new enterprise funded by venture capital.

Any joint effort or application house would need to be independent of any robot-making parent company so that users believed they were getting impartial advice.

We expect that this joint effort application house could be self-sustaining in the medium to long term. There will be a reluctance to work with the joint effort initially because:

- they will be relatively unknown, offering a new service;

- only some of the workers will start with any significant robot and/or mining experience although all would need significant engineering experience.

It is conceivable that government sources would be needed to initially organize this joint effort application house and to support the initial developmental phases.

The mining equipment suppliers are interested in developing first stage robotics only if the mining companies make a request.

The mining equipment manufacturers are predominantly multi-nationals with their research laboratories outside of Canada. Over 70% of the branch plants are straight assembly plants with the extent of their R & D being modification of a machine.

A couple of the firms in Canada have gone one step further.

1) Joy Canada Inc.
   - connected a microprocessor to a drill jumbo
   - the next step is programmable drill patterns.

2) Jarvis Clarke Inc.
   - developed the remote controlled LHD
   - developing an electric trolley system
   - interested in robotics, and have looked at the Columbia Space Arm

The majority of Canadian robotics experts have given very little thought of applications in mining. A further complication is that the manufacturing robotic experts lack mining knowledge.

It is therefore apparent that the initial coordination of the joint effort must be catalysed by concerned government.

7.6 Encourage Mining Robotic Commercial Ventures

In order to transfer technological developments to private industry, the government should support and encourage commercial ventures in mining robotics.

The goals of this subprogram would be to provide:

- an information base to new ventures interested in mining robotics;

- support of market and economic justification;

- initial capital financing for potentially viable ventures;

- ongoing research support.

Commercial ventures in mining robotics will likely only occur after the overall awareness within the mining industry has matured.

7.7 The Role Of EMR/CANMET In The Mining Robotics Program

Apart from the R & D area, where government has traditionally provided much of the finance, the main EMR/CANMET activity should be to act as a catalyst and source of information.

A small steering group for mining robot development, consisting mainly of mining companies, engineering applications and machinery companies and government seems the best way to keep to the targets. This steering group may be the precursor to the joint effort application house.

Specific EMR/CANMET functions under each of the subprograms are identified in the following discussion.

1) Promotion of Research & Development

The research program needs to be coordinated so that several basic criteria are established:

- minimum overlap and maximum relevance to mining needs;

- research is done in a timely way to meet commercial needs;

- short term research work should be oriented towards commercialization;

- cost targets are established and maintained.

To provide the R & D effort needed and the degree of industry participation required, EMR/CANMET will need to:

- contribute to all levels of R & D, but ensure that mining companies contribute enough to be committed to the work;

- allocate projects so that R & D is carried out by researcher/mining company partnerships rather than by researchers alone, both sides contributing people and money;

- establish detailed information concerning future mining technique developments and trends;

- undertake specific long term robotic research projects that are beyond the scope and means of mining companies.

2) Industry Awareness

The awareness campaign will not take place unless EMR/CANMET, companies, and research organizations make the effort. The main EMR activities would be:

- planning a campaign;
- professional design of materials for awareness presentations;
- providing people to do the critical mine presentations;
- sponsorship of joint U.S./Canadian interaction to further develop application areas.
- approach mining associations to persuade them that robot workshops are in their members interest;
- encourage "shop windows" when a good robot installation is developed -- it should be used as an example to others.

3) Sponsorship of the Joint Effort Development Group/Application House

Due to the lack of awareness of robotics potential, and the traditional complacent approach to innovation by Canadian mining companies, EMR will likely have to coordinate and direct the start-up phases of the joint effort, both financially and structure-wise.

There are a host of companies that have indicated interest in mining robotics. Typical of these companies are:

Jarvis Clarke
Joy Manufacturing
Kidd Creek Mines
INCO
Denison Mines
Spar Aerospace.

Since the joint effort application house is envisaged to eventually be self sustaining, the support of some engineering concern to spearhead the effort would be initially advisable.

4) Encouragement of Commercial Ventures

EMR's major role here is as an information source and as a supplier of and/or coordinator of financial incentives to establish commercial ventures. This may be through:

- support of feasibility analysis
- direct grants
- loan guarantees

It is important to ensure an active level of financial and resource participation is provided by private companies to ensure a long term directed effort.